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Technical Report

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DURABILITY ASSESSMENT OF THE
M313 EXPANDABLE VAN
DESIGN MODIFICATIONS

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13. ABSTRACT *(Maximum 200 words)*
This report describes the testing of the M313 6-ton expandable van in TACOM's Physical Simulation Laboratory. Design modifications were performed to fix several problem areas. The van was mounted to a high-performance motion simulator which excited the system by imparting realistic dynamic motions. A fifth-wheel spherical bearing fixture was designed and utilized to simulate the prime mover-trailer interaction.

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Preface

This report presents the full-scale motion base simulation of an M313 trailer. Questions regarding motion base simulation of vehicles and/or components are to be referred to the U.S. Army Tank-Automotive Command, ATTN: System Simulation and Technology Division, AMSTA-RY, Warren, MI 48397-5000, Telephone: AUTOVON/DSN 786-6228, Commercial (313) 574-6228.

1.0 Introduction

This report, prepared by the System Simulation and Technology Division of the Directorate for Tank-Automotive Technology; U.S. Army Tank-Automotive Command (TACOM), describes the testing of the M313 6-ton expandable van which was performed at TACOM's full-scale Physical Simulation Laboratory.

1.1 Background of the M313 Semitrailer

In 1989, two M313 semitrailers were subjected to tests of 6,000 miles each at Aberdeen Proving Grounds (APG). One of the trailers was withdrawn from the test after completing 3,279 miles because its left floor folding panel became detached from its hinges. The other trailer completed the 6,000 mile test after hinge mounting modifications performed at 3,450 miles.

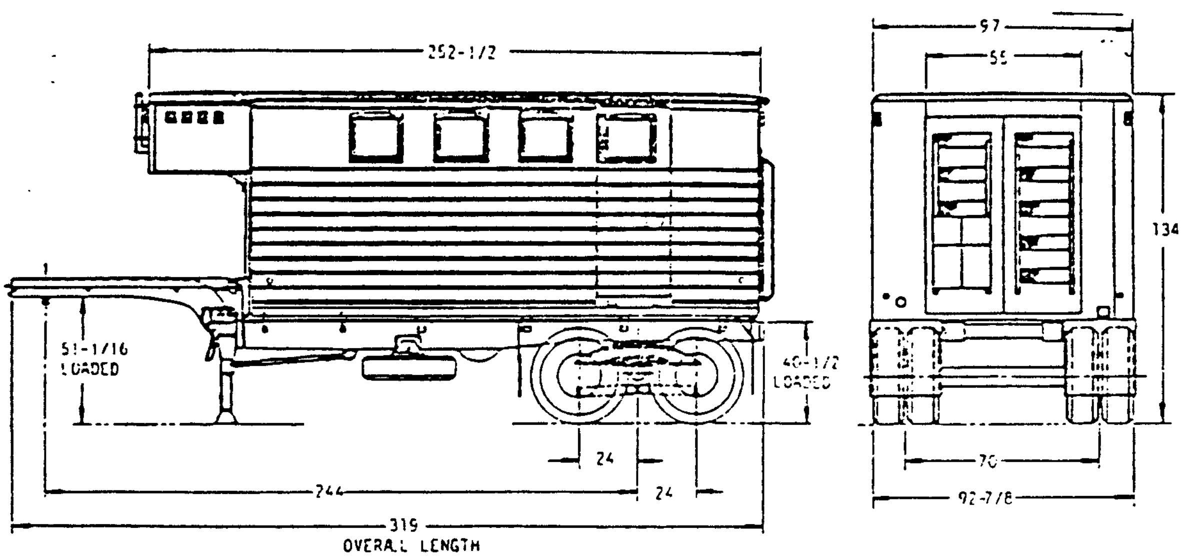
Screws and bolts became loose over the entire van body, including the screws that hold the folding floor panels to their hinges. A floor panel on one of the trailers separated from the trailer after approximately 3,000 miles. Cracks were detected either on or adjacent to each of four support beam corner brackets. In addition, many components of the van body were excessively worn, permanently deformed or broken. Consequently, neither of the two semitrailers were able to complete the 6,000 mile test without at least one durability failure resulting from cracking or permanent deformation of various components or assemblies. The M313 semitrailers, therefore, failed to meet the reliability and durability criteria as required in the specification.

Many of the problems discovered during the tests were attributed to a combination of possible design or fabrication defects, or the possibility that the trailers may have been operated for some time with one or more of the interior panels unlocked. This situation allowed the M313 van body framework to flex more, causing the corner brackets structures to fail.

To eliminate the above-mentioned problems, Engineering Design Division engineers redesigned of the corner post reinforcement brackets panel hinge fasteners. The modification work was performed in the Fabrication Division's facility.

1.2 Item Description

The vehicle is designed to provide a mobile semitrailer van shop for the installation of maintenance shop sets. It has an expandable van body mounted on an M295A1 chassis. The van body is of double-wall construction consisting of an outer aluminum skin and an inner plywood covering. The van body expands to approximately twice the volume it encloses, when retracted. It is also equipped with an electrical system 120/220 V-AC and receptacles. The front bonnet has interface connections for two 60,000 BTU multifuel burning heaters and one 36,000 BTU air conditioner. The vehicle is furnished with stabilizing jacks and two aluminum boarding ladders. See Figure 1.



M313 Semitrailer
Figure 1

2.0 Test Objectives

The objectives of this test were to validate the conversion concept, design modification changes, manufacturing methods, conformance to safety requirements and to test the M313 trailer for adequacy of quality assurance procedures.

Also the motion base test was to validate the fifth-wheel fixture concept and provide test data for concept evaluation and dynamic model verification of the M313 prime mover and trailer.

3.0 Dummy Load Configuration

The M313 payload configuration consisted of 9,000 lbs of dummy load evenly distributed, with vertical center of gravity 15" above the floor level. The horizontal center of gravity was located 128" from the rear of the trailer on the center line of the trailer. In addition, there were 2,000 lbs of load on the front platform (above the fifth-wheel) with the vertical center of gravity 15" above the platform. Also there were 600 lbs of load in the bonnet of the trailer.

4.0 Inspection

Inspections were performed by the test engineers and associate technicians to determine the conditions of the M313 trailer prior to and during the test. A variety of problems were encountered during the APG field tests; therefore, it was mandatory to closely monitor the entire 4,500-mile test. Inspection requirements, which complied with TM 9-2330-238-14&P, were as follows:

Initial

1. Lubricate and prepare the vehicle according to TM 9-2330-238-14&P
2. Set tire pressure to 40 PSI.
3. Assure that the dummy load is secured adequately inside and outside the trailer.
4. Assure that all the expansible wall pins are properly engaged with the wall sockets.
5. Check all fasteners inside the trailer.
6. Check all safety chains and cables used to prevent the trailer from overturning.
7. Lubricate the kingpin fixture.
7. Check all wall clamps and adjust their tension, if necessary.
9 Perform visual inspection of the vehicle and search for any mechanical damage or abnormalities.

Ongoing

1. Check tire pressure every 300 miles
2. Rotate tires every 300 miles
3. Lubricate the kingpin fixture as often as necessary
4. Check the expansible wall pin, sockets and all corner posts for cracks after first 150 miles and thereafter every 300 miles.

5. Check dummy load and its fasteners after first 150 miles and thereafter every 300 miles.
6. Perform visual inspection every 300 miles.
7. Perform simulator maintenance, if necessary.
8. Lubricate the trailer according to TM-2330-238-14&P.

5.0 Conclusions and Recommendations

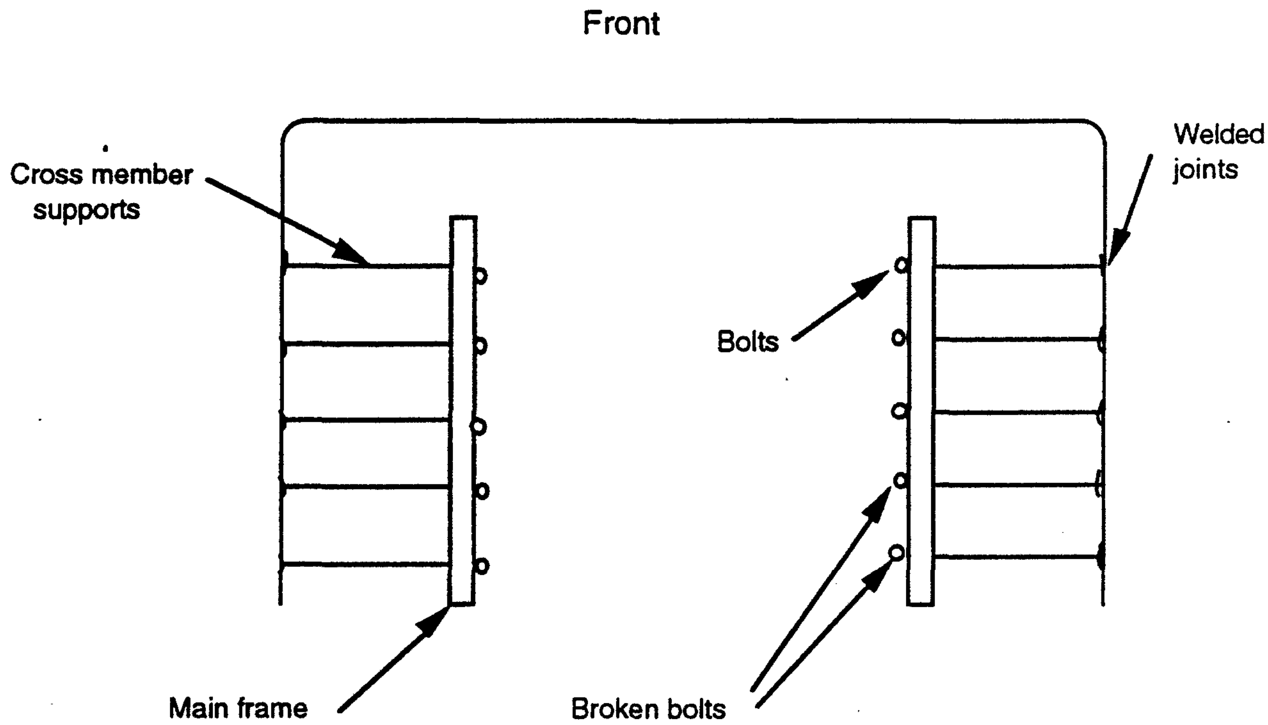
The motion base simulator proved to be an accurate and efficient method for performing a durability assessment of the M313 van. Summarizing the conclusions of the test, it was shown that all modifications performed on the M313 trailer worked extremely well. The pins and bushings were found to be only slightly worn due to proper material compatibility and design changes. By comparison, the original pins and bushings were sheared off or deformed after 3,000 miles of field testing at APG. Consequently, this allowed the unlocked panels to move, causing the M313 van body framework to flex excessively. As a result, the corner bracket posts were failing.

There was one small problem encountered during the test. During the inspection at 3,600 miles two bolts on the cross member supports (directly under the front platform) were found to be broken, and the remaining ones were found to be loosened. Refer to Figure 2. Our recommendation would be to use No. 242 or 262 Locktite to prevent bolts loosening. Also it should be emphasized that the current design configuration, where one end of the cross member is welded and another bolted, is questionable. In addition some of the cross members are covered with the steel plate, which has small-bolt access holes; consequently, access to the bolts is very difficult.

6.0 Discussion

6.1 Background

A motion simulator was specially designed and built to provide the secondary and cross-country profile roll, pitch, and vertical motions to the trailer. The simulator consists of four actuators, each supporting a custom platen on which a trailer tire is centered upon. A fifth actuator is connected via a spherical bearing to the fifth-wheel attachment on the



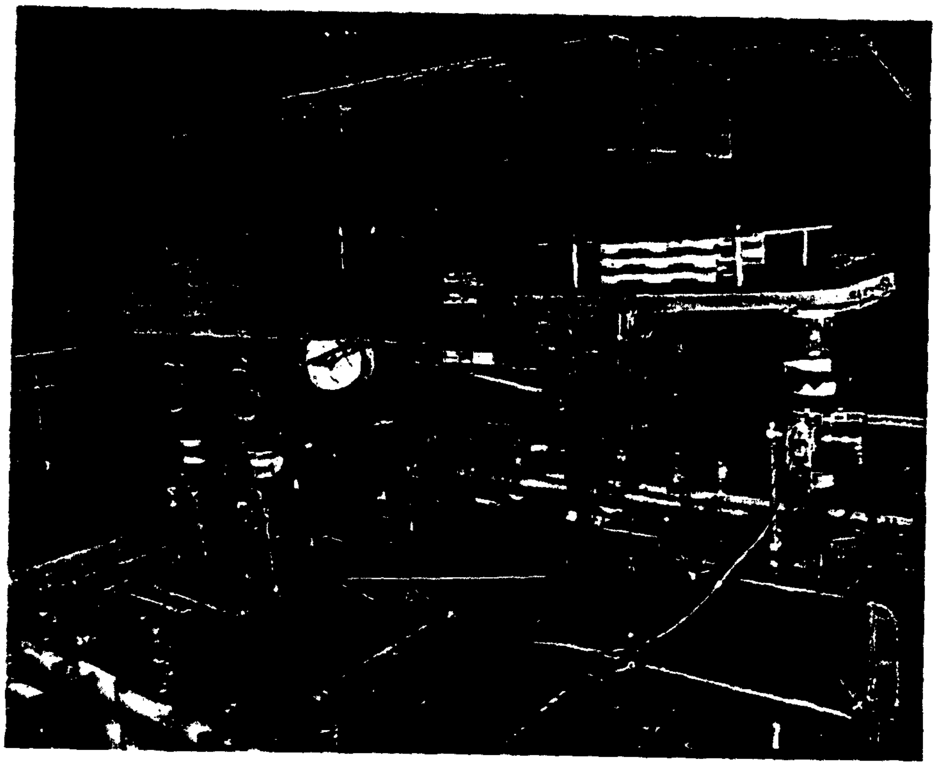
Bottom view of M313 trailer platform configuration showing mainframe and cross-member supports.
Figure 2

trailer frame. The simulator uses electrohydraulic actuators to produce motion on the test item. See Figure 3.

A high-resolution dynamics model of the 313 and prime mover was produced by means of the well-documented Dynamic Analysis and Design System (DADS) method. Simulations were run to determine the motion states of the fifth-wheel and other parameters of interest.

In operation, a Computer Automated Measurement and Control (CAMAC) system creates actuator commands which synergistically produce the vertical and rotational motion requirements. The CAMAC system is interfaced to the RDE Center Supercomputing Network and motion controllers that output a servo current drive signal to each actuator. The simulator is controlled by an operator at a control console.

All simulator design, assembly, integration, and software development were accomplished within TACOM's RDE Center.



M313 Trailer on Simulator
Figure 3

6.1.1 Performance Specification

The performance envelope of the simulator is given in Table 1.

Table 1 Performance Summary of Simulator

Parameter	Value
Payload	12,000 pounds plus trailer
Axes	Roll, Pitch, and Vertical
Maximum excursions	
Vertical	+- 9 inches
Pitch	+- 2.5 degrees
Roll	+- 7 degrees
Maximum acceleration 6 g's (actuator)	
Positional bandwidth	12 hertz

6.1.2 Simulator Control System

The control system consists of the CAMAC system, servo controllers and servo valves ported to the actuators. TACOM engineers write software on the CAMAC system, which sends real-time, scaled actuator commands through five 12-bit digital-to-analog converters at a clock rate of 100 samples per second. The software is written such that actuator commands are provided continuously for 12 hours or more without replenishing the CAMAC system with additional road profile data. These commands are received by five servo controllers which supply current signals to drive the servovalves on the actuators. They do this while maintaining actuator loop control.

6.2 Profile Selection

The motion simulator is supplied with actuator commands that reproduce the dynamic effects of a variety of secondary road and cross-country terrains. The Comparison Test Directive summarizes the mission profile for the M313. Courses and simulated speeds were selected from this library that match characteristics of those from the directive. These are specified in Table 2.

Table 2 Selected Courses

Course type	Bump max	Simulated Speed
Gravel		
- Churchville 6	1.8 inch pk-pk	25 mph
- Churchville 7	1.2 inch pk-pk	25 mph
Level Cross-Country		
- APG 37	4.4 inch pk-pk	20 mph
- Letourneau 5*	5.5 inch pk-pk	15 mph
Hilly Cross-Country		
- Letourneau 4*	3.5 inch pk-pk	20 mph
Belgian Block**		
- Churchville 7	1.2 inch pk-pk	25 mph

* Letourneau courses run were actually one half amplitude of the original Letourneau courses profiled at Waterways Experiment Station, Vicksburg, Miss.

** Belgian block profile not available on computer. Churchville 7 was used instead.

Members of the Light Tactical Vehicle Branch (AMSTA-QWL) were consulted for their concurrence with the selection of this profile/speed scenario. These scenarios were executed on the simulator and agreement was reached on all simulations.

6.3 Test Execution

The M313 6-ton expansible van was subjected to 4,500 miles of simulated road profile as detailed in Table 3.

Table 3 Test Mileage Breakdown

Course	Miles with Payload	Speed
Gravel		
- Churchville 7	2,175	25 mph
Level Cross-Country		
- APG 37	625	20 mph
- Letourneau 5_50	625	15 mph
- Letourneau 4_50	625	20 mph
Hilly Cross-Country		
- Churchville 6	450	25 mph

	4,500	

Testing commenced August 2, 1991 and concluded on September 10, 1991. The test course mileage was accumulated in five (5) cycles of 900 miles each.

Simulator performance was monitored throughout the test. This ensured that the motion simulator produced the dynamics intended for each profile simulated.

6.4 Data Acquisition

The motion simulator and M313 6-ton expansible van were instrumented with a variety of transducers. The data collected provide the engineering community with position, velocity and acceleration information to evaluate test results. It is also used to provide the design and test engineer with the required parameters needed to diagnose simulator or vehicle failures. The data collected are summarized in Table 4. The data were recorded digitally using the CAMAC system and were low pass filtered at 50 hertz and recorded at 100 samples per second. The data are retained in the System Simulation and Technology Division's computer archives.

The specific transducers and amplifiers used in the data collection effort are detailed in Table 5.

6.5 Data Analysis

The analysis indicates that the five hydraulic actuators tracked their command inputs extremely well throughout the test. Thus the simulator was subjecting the trailer to the proper motion profile. The suspension system has its dominant resonance at 10 to 12 hertz. The trailer frame and structure produce a major resonance at 6 hertz throughout the trailer body (including modified areas). These resonance components occur on every simulation scenario and most likely contributed to the incidents cited in this report.

There were 21 signals of interest recorded throughout the testing of the M313 trailer. Tables 6 through 10 summarize statistics calculated from each signal for every bump course. An in-depth analysis was performed on eight selected signals from each bump course profile used in the following sections. These selected signals are;

- Right-rear spindle acceleration
- Right-rear ceiling acceleration
- Left-front ceiling acceleration
- Fifth-wheel acceleration
- Right-rear actuator command
- Right-rear actuator response
- Fifth-wheel actuator command
- Fifth-wheel actuator response

Analysis was performed in the time and frequency domains. Plots from these selected signals are contained in Figures 4 through 70.

Table 4 M313 Data Acquisition

Accelerometers	Range	Scale Factor	Bandwidth	Filter
1. LR spindle	+- 10 g	+0.5 vdc/g	dc - 100 hz	50 hz Sicos
2. RR spindle	+- 10 g	+0.5 vdc/g	dc - 100 hz	50 hz Sicos
3. LF spindle	+- 10 g	+0.5 vdc/g	dc - 100 hz	50 hz Sicos
4. RF spindle	+- 10 g	+0.5 vdc/g	dc - 100 hz	50 hz Sicos
5. 5th wheel on top @c/l	+- 10 g	+0.5 vdc/g	dc - 100 hz	50 hz Sicos
6. LR ceiling @ bracket	+- 10 g	-1.0 vdc/g	dc - 100 hz	50 hz Sicos
7. RR ceiling @ bracket	+- 10 g	-1.0 vdc/g	dc - 100 hz	50 hz Sicos
8. LF ceiling @ bracket	+- 10 g	-1.0 vdc/g	dc - 100 hz	50 hz Sicos
9. RF ceiling @ bracket	+- 10 g	-1.0 vdc/g	dc - 100 hz	50 hz Sicos
Gyros				
10. Pitch underneath on	+- 60 d/s	+63.0 mv/d/s	dc - 25 hz	50 hz Sicos
11. Roll structural member	+- 60 d/s	+63.0 mv/d/s	dc - 25 hz	50 hz Sicos
Commands				
12. LR CAMAC #1 dac	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
13. RR CAMAC #2 dac	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
14. LF CAMAC #3 dac	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
15. RF CAMAC #4 dac	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
16. 5th whl CAMAC #5 dac	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
LVDT's				
17. LR Act #1	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
18. RR Act #2	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
19. LF Act #3	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
20. RF Act #4	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos
21. 5th whl Act #5	+- 6 inch	+1.0 vdc/inch	dc - 50 hz	50 hz Sicos

Table 5 Instrumentation Documentation

Ch	Device	Location	Model Number	Serial Number
1	Accelerometer	Left-rear spindle	Setra 141B	298505
2	Accelerometer	Right-rear spindle	Setra 141B	298508
3	Accelerometer	Left-front spindle	Setra 141B	298504
4	Accelerometer	Right-front spindle	Setra 141B	298506
5	Accelerometer	Fifth-wheel spindle	Setra 141B	298507
6	Accelerometer	Left-rear box	Statham A69TC-5-350	17790
7	Accelerometer	Right-rear box	Statham A69TC-5-350	17002
8	Accelerometer	Left-front box	Statham A69TC-5-350	17787
9	Accelerometer	Right-front box	Statham A69TC-5-350	17780
10	Rate transducer	Pitch axis	Humphrey RT03-0108-1	106
11	Rate transducer	Roll axis	Humphrey RT03-0108-1	105
17	Actuator	#1, left-rear	Istron 306-25s	3236
18	Actuator	#2, right-rear	Istron 306-25s	3232
19	Actuator	#3, left-front	Istron 306-25s	3228
20	Actuator	#4, right-front	Istron 306-25s	3237
21	Actuator	#5, fifth-wheel	Istron 306-25s	3227
17	Servo valve	#1, left-rear	Istron 1640E	198
18	Servo valve	#2, right-rear	Istron 1640E	None
19	Servo valve	#3, left-front	Istron 1640E	152
20	Servo valve	#4, right-front	Istron 1640E	618
21	Servo valve	#5, fifth-wheel	Istron 1640E	620
1	Amplifier	Left-rear spindle	Measurements Co. 2310	75957
2	Amplifier	Right-rear spindle	Measurements Co. 2310	75933
3	Amplifier	Left-front spindle	Measurements Co. 2310	75958
4	Amplifier	Right-front spindle	Measurements Co. 2310	75960
5	Amplifier	Fifth-wheel spindle	Measurements Co. 2310	75963
6	Amplifier	Left-rear box	Ectron 418APW-5	3988
7	Amplifier	Right-rear box	Ectron A418-12iw-16	3996
8	Amplifier	Left-front box	Ectron A418-12iw-16	2659
9	Amplifier	Right-front box	Ectron A418-12iw-16	2663

6.5.1 APG 37 at 20 mph

Table 6 Vehicle Response and Input Characteristics

Course: Aberdeen 37 Speed: 20 mph

Channel	Unit	RMS	Max	Min
1. LR spindle accel.	g	1.69	6.22	-5.17
2. RR spindle accel.	g	1.85	6.65	-5.70
3. LF spindle accel.	g	1.65	4.99	-5.03
4. RF spindle accel.	g	1.86	5.87	-5.59
5. Fifth-wheel accel.	g	0.367	1.53	-1.44
6. LR ceiling accel.	g	0.341	1.14	-1.09
7. RR ceiling accel.	g	0.350	1.20	-1.13
8. LF ceiling accel.	g	0.268	0.816	-0.862
9. RF ceiling accel.	g	0.261	0.771	-0.827
10. Pitch of trailer	deg/sec	2.38	7.02	-7.55
11. Roll of trailer	deg/sec	0.251	0.931	-0.889
12. LR command	inches	0.836	1.82	-2.60
13. RR command	inches	0.841	1.83	-2.62
14. LF command	inches	0.839	1.83	-2.60
15. RF command	inches	0.841	1.83	-2.61
16. Fifth-wh. cmd.	inches	0.944	1.84	-3.03
17. LR LVDT fdbk.	inches	0.806	1.77	-2.50
18. RR LVDT fdbk.	inches	0.837	1.81	-2.58
19. LF LVDT fdbk.	inches	0.836	1.81	-2.58
20. RF LVDT Fdbk.	inches	0.838	1.81	-2.58
21. Fifth-wh. LVDT	inches	0.952	1.84	-3.04

Right-rear spindle acceleration.

Time plots show typical peak accelerations of 7 g's. The autospectrum indicates a maximum of 0.9 g at 10 Hz (Figure 5). The plot also has spikes at 20 Hz and at 40 Hz, which are probably harmonics of the 10 Hz component. When this plot is compared to the two plots of the ceiling accelerometers, similarities can be seen in the frequencies below 5 Hz. These similarities are primarily due to the frequency content of the bump course. This similarity is seen in the rear ceiling accelerometer more than in the front because of the proximity of the rear accelerometer to the wheels. This similarity occurs to a lesser extent in the plots of the command and feedback autospectrums. The components above 5 Hz are due to the dynamics of the suspension system, especially the large component at 10 Hz. This 10-Hz component is also present in the time history in Figure 4.

Right-rear and left-front ceiling acceleration.

These plots are very similar to each other, both in the frequency and time domains, which should be expected. The time plots show typical peak accelerations of 0.7 g. The autospectrums are in Figures 8 and 9 while the time histories are in Figures 6 and 7. Both of the autospectrums have their maximums at 6 Hz, which are 0.2 g and 0.17 g for the right-rear and left-front, respectively. This 6 Hz component is due to the resonant frequency of the chassis and frame of the trailer. Both autospectrums resemble the shape of the bump course autospectrum below 6 Hz. The autospectrums are similar to each other throughout the plotted spectrum; however, the rear accelerometer has more frequency content above the 6-Hz component, especially in the 6-to 10-Hz range. This is due to the fact that the rear accelerometers are located directly above the rear wheels, which have more high-frequency content than the fifth-wheel input does. The 6 Hz component is also seen in the autospectrum of the fifth-wheel accelerometer data, which is shown in Figure 11.

Fifth-wheel acceleration.

An amplitude vs. time plot in Figure 10 shows typical peak accelerations of 1.5 g. The spike at 6 Hz, which was seen in the previous two autospectrums, also occurs here. Refer to Figure 11. Here, however, its amplitude is only 0.09 g peak. The reason for this is that the fifth-wheel accelerometer was attached to the tongue of the trailer, above the fifth-wheel attachment. Thus this accelerometer was also exposed to the vibrations of the resonating frame. The frequency content of this accelerometer gradually increases with increasing frequency in the range of 20 to 50 Hz. This is due to noise input from the actuator and not the bump course or the dynamics of the trailer.

Right-rear actuator command and response.

The spectrums in Figures 14 and 15 show that the feedback follows the command fairly nicely until the frequency exceeds 10 Hz, which is the cutoff frequency of the actuator control system. It is evident that APG 37 contains a broadband frequency content. As can be seen in Figures 12 and 13, the tracking ability of the control system is more than adequate to replicate the given command profile. The control system tracks well, but is less responsive in the high-frequency ranges of the command input.

Fifth-wheel actuator command and response.

Figures 18 and 19 show that the feedback follows the command nicely up to about 10 Hz and then begins to roll off above 10 Hz. The fifth-wheel command has less high-frequency content than the right-rear command, as can be seen from the autospectrums and the time histories in Figures 16 and 17. The feedback differs from what would ordinarily be expected in that it contains a large component at 6 Hz. This is due to the direct link between the trailer and the fifth-wheel actuator. The frame, ,resonating at 6 Hz, transmits this vibration to the actuator through the direct-coupled fifth-wheel. This, in turn, is detected in the LVDT output. This effect, although small, is obvious when the frequency response function of this actuator is calculated.

6.5.2 Churchville 6 at 25 mph

Right-rear acceleration.

The autospectrum (Figure 21) has the most significant frequency content in the range of 10 to 20 Hz, where the maximum reaches about 0.35 g peak at 12 Hz. This maximum is due to the dynamics of the suspension system. This same 10-Hz component shows up in all of the spindle accelerometer data. The frequency content below 10 Hz is directly related to the bump course. This 10-Hz component dominates the time domain plot in Figure 20 with typical peak accelerations of 4 g.

Right-rear and left-front ceiling acceleration.

The time plots in Figures 22 and 23 show typical peak accelerations of 0.7 g. The two autospectrums in Figures 24 and 25 have the same peaks at 6 Hz as the ones from APG 37. They are, however, lower in magnitude with 0.12 g and 0.13 g peak for the right-rear and left-front respectively. These are again due to the resonance of the frame. The two plots are similar in the frequency ranges below 6 Hz (due to the bump course), but the rear accelerometers have more frequency content above 6 Hz because of the location of the rear accelerometers with respect to the rear wheels. This difference in frequency content can also be detected in the time domain plots.

Fifth-wheel acceleration.

The time plot in Figure 26 shows typical peak accelerations of 1.0 g. The autospectrum in Figure 27 has a 6-Hz component from the resonating frame with a magnitude of 0.4 g peak. The bump course is the cause of the frequency content below the 6-Hz component. This is why it also resembles the ceiling accelerometer autospectrums in the low-frequency range. The frequency content also rises in magnitude between 20 and 50 Hz and is due to negligible noise in the actuator. The time history would

Table 7 Vehicle Response and Input Characteristics

Course: Churchville 6 Speed: 25 mph

Channel	Unit	RMS	Max	Min
1. LR spindle accel.	g	1.03	4.35	-4.52
2. RR spindle accel.	g	1.03	4.33	-4.31
3. LF spindle accel.	g	1.05	3.94	-4.76
4. RF spindle accel.	g	1.06	4.23	-4.37
5. Fifth-wheel accel.	g	0.294	1.19	-1.26
6. LR ceiling accel.	g	0.240	0.904	-0.842
7. RR ceiling accel.	g	0.245	0.895	-0.881
8. LF ceiling accel.	g	0.203	0.607	-0.672
9. RF ceiling accel.	g	0.197	0.593	-0.660
10. Pitch of trailer	deg/sec	1.19	3.13	-4.72
11. Roll of trailer	deg/sec	0.173	0.638	-0.602
12. LR command	inches	0.248	0.860	-0.790
13. RR command	inches	0.249	0.863	-0.794
14. LF command	inches	0.250	0.891	-0.821
15. RF command	inches	0.252	0.896	-0.827
16. Fifth-wh. cmd.	inches	0.220	0.399	-0.523
17. LR LVDT fdbk.	inches	0.229	0.752	-0.629
18. RR LVDT fdbk.	inches	0.240	0.771	-0.583
19. LF LVDT fdbk.	inches	0.242	0.776	-0.577
20. RF LVDT Fdbk.	inches	0.242	0.770	-0.633
21. Fifth-wh. LVDT	inches	0.221	0.404	-0.533

be much smoother if it were not for the high-frequency components between 20 and 50 Hz.

Right-rear actuator command and response.

The feedback follows the command fairly well up to 10 Hz which is the actuator cutoff frequency. This can easily be observed from the autospectrums in Figures 30 and 31. The effect of the 10-Hz cutoff can be seen in the time domain plots of the command and feedback in Figures 28 and 29. It is evident that the actuator has difficulty tracking the three severe bumps in this course because of the 10-Hz cutoff. The command has an even distribution of high and low frequencies.

6.5.3 Churchville 7 at 25 mph

Table 8 Vehicle Response and Input Characteristics

Course: Churchville 7 Speed: 25 mph

Channel	Unit	RMS	Max	Min
1. LR spindle accel.	g	0.953	3.76	-3.53
2. RR spindle accel.	g	1.05	3.83	-3.78
3. LF spindle accel.	g	0.975	3.11	-3.38
4. RF spindle accel.	g	1.10	3.77	-3.90
5. Fifth-wheel accel.	g	0.269	1.06	-1.03
6. LR ceiling accel.	g	0.265	0.814	-0.712
7. RR ceiling accel.	g	0.271	0.852	-0.741
8. LF ceiling accel.	g	0.220	0.585	-0.571
9. RF ceiling accel.	g	0.214	0.550	-0.568
10. Pitch of trailer	deg/sec	1.30	3.23	-3.53
11. Roll of trailer	deg/sec	0.172	0.553	-0.557
12. LR command	inches	0.189	0.627	-0.519
13. RR command	inches	0.190	0.630	-0.522
14. LF command	inches	0.190	0.623	-0.516
15. RF command	inches	0.191	0.627	-0.520
16. Fifth-wh. cmd.	inches	0.210	0.455	-0.496
17. LR LVDT fdbk.	inches	0.181	0.607	-0.493
18. RR LVDT fdbk.	inches	0.180	0.581	-0.487
19. LF LVDT fdbk.	inches	0.180	0.594	-0.482
20. RF LVDT Fdbk.	inches	0.182	0.595	-0.484
21. Fifth-wh. LVDT	inches	0.215	0.474	-0.502

Right-rear spindle acceleration.

The time plot in Figure 32 shows typical peak accelerations of 4 g. The autospectrum in Figure 33 indicates frequency content between 10 and 20 Hz, with a maximum of 0.45 g peak at 12 Hz. This is due to the dynamics of the suspension system. The bump course is responsible for everything below the 10 Hz component. This autospectrum has significant components above 10 Hz, unlike the APG or Letourneau runs, because the Churchville courses used in this test have significantly more frequency content in the higher frequencies. The 10-Hz component can also be seen in the time domain plot.

Right-rear and left-front ceiling acceleration.

The time plots in Figures 34 and 35 show typical peak accelerations of 0.7 g's. The autospectrums in Figures 36 and 37 show the 6-Hz component from the frame resonance. The magnitudes of these components are 0.13 g peak for both the right-rear and the left-front accelerometers. They are similar to each other below this frequency. The rear accelerometers have more frequency content above 6 Hz, due to their proximity to the rear wheels; the rear actuator inputs contain higher frequencies than the fifth-wheel command. The rear accelerometer data also has a 0.051 g peak spike at 10 Hz which is from the resonance of the suspension; this is not present in the front-ceiling acceleration.

Fifth-wheel acceleration.

The time plot in Figure 38 shows typical peak accelerations of 0.8 g. The autospectrum in Figure 39 has a significant component of 0.5 g peak at 6 Hz, which is from the resonating frame. The frequency components below this frequency are due to the fifth-wheel command. The spectrum has a gradual increase in magnitude between 20 and 50 Hz.

Right-rear actuator command and response.

The feedback follows the command nicely up to the cutoff frequency of 10 Hz, as demonstrated in the two autospectrums in Figures 42 and 43. Like Churchville 6, this course offers an evenly distributed range of frequency inputs which translates into a flatter spectrum than the other courses. The quality of control system tracking can be seen in the time domain by observing Figures 40 and 41.

6.5.4 Letourneau 4[1/2] at 20 mph.

Table 9 Vehicle Response and Input Characteristics

Course: Letourneau 4[1/2]   Speed: 20 mph

Channel	Unit	RMS	Max	Min
1. LR spindle accel.	g	0.723	3.08	-2.66
2. RR spindle accel.	g	0.752	2.84	-2.39
3. LF spindle accel.	g	0.710	3.00	-2.80
4. RF spindle accel.	g	0.753	3.02	-2.45
5. Fifth-wheel accel.	g	0.348	1.67	-1.72
6. LR ceiling accel.	g	0.294	1.14	-0.903
7. RR ceiling accel.	g	0.301	1.24	-0.887
8. LF ceiling accel.	g	0.242	0.819	-0.741
9. RF ceiling accel.	g	0.236	0.860	-0.679
10. Pitch of trailer	deg/sec	2.24	6.65	-7.45
11. Roll of trailer	deg/sec	1.54	5.82	-4.55
12. LR command	inches	0.606	1.35	-1.79
13. RR command	inches	0.691	1.45	-2.04
14. LF command	inches	0.608	1.36	-1.80
15. RF command	inches	0.690	1.45	-2.05
16. Fifth-wh. cmd.	inches	0.755	1.54	-2.52
17. LR LVDT fdbk.	inches	0.582	1.31	-1.74
18. RR LVDT fdbk.	inches	0.685	1.43	-2.01
19. LF LVDT fdbk.	inches	0.604	1.34	-1.79
20. RF LVDT Fdbk.	inches	0.686	1.44	-2.01
21. Fifth-wh. LVDT	inches	0.761	1.54	-2.55

Right-rear spindle acceleration.

The time plot in Figure 44 shows typical peak accelerations of 3 g. The autospectrum in Figure 45 has a significant component at 10 Hz, with a magnitude of 0.4 g peak. This component does not extend all the way to 20 Hz as it did for the Churchville courses. The Letourneau courses used here do not have as much high-frequency components as the Churchville courses; therefore, they contribute less to the accelerations above 10 Hz. The 10-Hz component is due to the suspension resonance. This autospectrum resembles the bump course and the ceiling accelerometers below 6 Hz.

Right-rear and left-front ceiling acceleration.

The time plots in Figures 46 and 47 show typical peak accelerations of 1.6 g. The autospectrums in Figures 48 and 49 contain a 6 Hz component of 0.16 g peak which is caused by the resonance of the frame of the trailer. The rear ceiling accelerometer has more magnitude than the front ceiling accelerometer, in the frequencies above the 6 Hz spike, due to its proximity to the wheels. The two autospectrums of the front and rear ceiling accelerometers do not differ from each other as much as they do for the higher frequency Churchville courses.

Fifth-wheel acceleration.

The time plot in Figure 50 shows typical peak accelerations of 1.6 g. The frame resonance component at 6 Hz has been observed in all of the autospectrums of the fifth-wheel acceleration data of other bump courses. Here it is observed in the autospectrum of Figure 51 with a magnitude of 0.05 g peak. This autospectrum also has a 0.1 g peak component at 2.1 Hz which is attributable to the bump course input.

Right-rear actuator command and response.

The feedback follows the command closely up to 10 Hz, which is the cutoff frequency of the control system. See the autospectrums of Figures 54 and 55. It is clear that this command produces a steeper downward slope than the Churchville courses do, and thus is weaker in the high-frequency range than the Churchville courses are. Due to the lack of high frequencies, the actuator follows the command better as portrayed in the time domain plots of Figures 52 and 53.

6.5.5 Letourneau 5[1/2] at 15 mph.

Right-rear spindle acceleration.

The autospectrum in Figure 57 has a 10-Hz component of 0.18 g peak, which is caused by the resonance of the suspension system. The time plot in Figure 56 shows typical peak accelerations of 10.0 g. Examining the time history reveals that the largest acceleration generated during the test is 10 g. This is caused by the sharp drop in the right command (Figure 56) at 24.2 seconds.

Right-rear and left-front ceiling acceleration.

Time plots in Figures 58 and 59 show typical peak accelerations of 1 g. The autospectrums in Figures 60 and 61 have a 6 Hz component with magnitudes of 0.09 g and 0.11 g peak for the right-rear and left-front ceiling accelerometers respectively. These components are due to the 6-Hz resonant frequency of the frame. The two autospectrums are similar to each other in the frequency ranges below 6 Hz. The rear accelerometers have slightly more frequency content in the ranges above 6 Hz, due to the proximity of the rear accelerometers to the rear wheels.

Table 10 Vehicle Response and Input Characteristics

Course: Letourneau 5[1/2] Speed: 15 mph

Channel	Unit	RMS	Max	Min
1. LR spindle accel.	g	0.609	4.01	-3.12
2. RR spindle accel.	g	0.641	8.49	-4.85
3. LF spindle accel.	g	0.602	3.43	-3.00
4. RF spindle accel.	g	0.638	5.00	-3.89
5. Fifth-wheel accel.	g	0.363	2.24	-1.81
6. LR ceiling accel.	g	0.271	1.14	-0.977
7. RR ceiling accel.	g	0.283	1.28	-1.02
8. LF ceiling accel.	g	0.246	0.937	-0.727
9. RF ceiling accel.	g	0.237	0.917	-0.735
10. Pitch of trailer	deg/sec	2.16	7.24	-8.61
11. Roll of trailer	deg/sec	1.89	5.43	-5.34
12. LR command	inches	1.03	2.49	-3.02
13. RR command	inches	0.976	2.61	-2.21
14. LF command	inches	1.03	2.49	-3.04
15. RF command	inches	0.977	2.60	-2.22
16. Fifth-wh. cmd.	inches	1.19	2.52	-3.31
17. LR LVDT fdbk.	inches	0.992	2.24	-2.85
18. RR LVDT fdbk.	inches	0.973	2.51	-2.20
19. LF LVDT fdbk.	inches	1.03	2.43	-2.87
20. RF LVDT Fdbk.	inches	0.973	2.52	-2.21
21. Fifth-wh. LVDT	inches	1.20	2.53	-3.33

Fifth-wheel acceleration.

This autospectrum has a 6-Hz component with a magnitude of 0.021 g peak. The largest component is 0.043 g at 1.2 Hz, due to the fifth-wheel command. The reason that the 6 Hz component is not dominant is that this bump course has significantly larger low-frequency components than high-frequency components. This autospectrum also has the high-frequency components introduced to the trailer by the fifth-wheel actuator, which is directly coupled to the trailer tongue. The time history of this acceleration is in Figure 62.

Right-rear actuator command and response.

The response autospectrum in Figure 67 closely resembles the command autospectrum of Figure 66 up to about 10 Hz, which is the actuator control system cutoff frequency. It can be seen that these autospectrums have more low-frequency components than high-frequency components. This is why the 6-Hz component is not dominant in the fifth-wheel accelerometer autospectrum. This course is low frequency in nature; therefore the actuator tracks the command very well except at 24.2 seconds where the previously-mentioned 10-g acceleration takes place. This is demonstrated in Figures 64 and 65.

6.6 Time and Autospectrum Plots

Time and autospectrum plots of the data recorded in this test are presented in Figures 4 through 67.

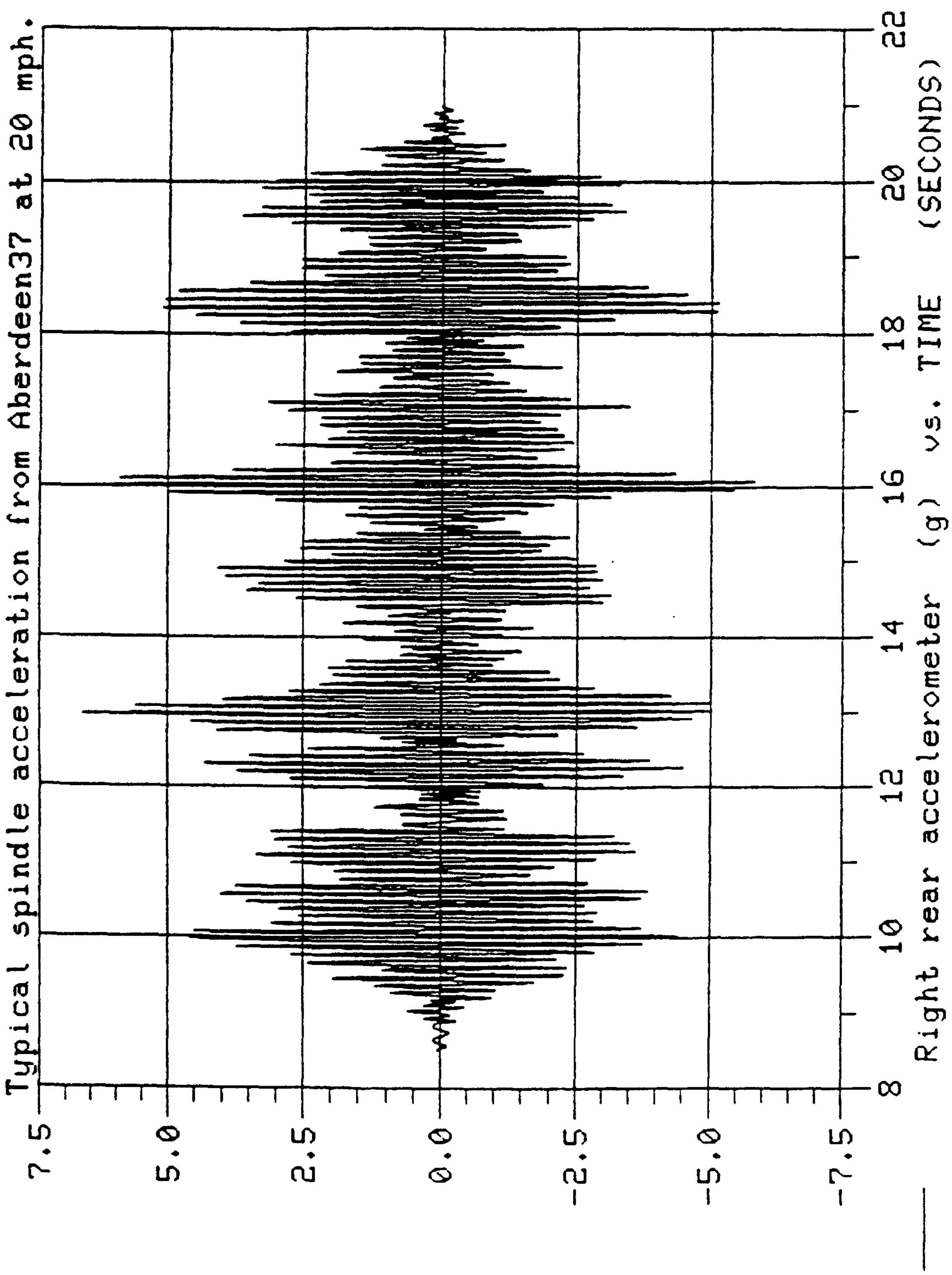

Typical spindle acceleration from Aberdeen37 at 20 mph.
Right rear accelerometer (g) vs. TIME (SECONDS)
7.5
5.0
2.5
0.0
-2.5
-5.0
-7.5
8
10
12
14
16
18
20
22

Figure 4

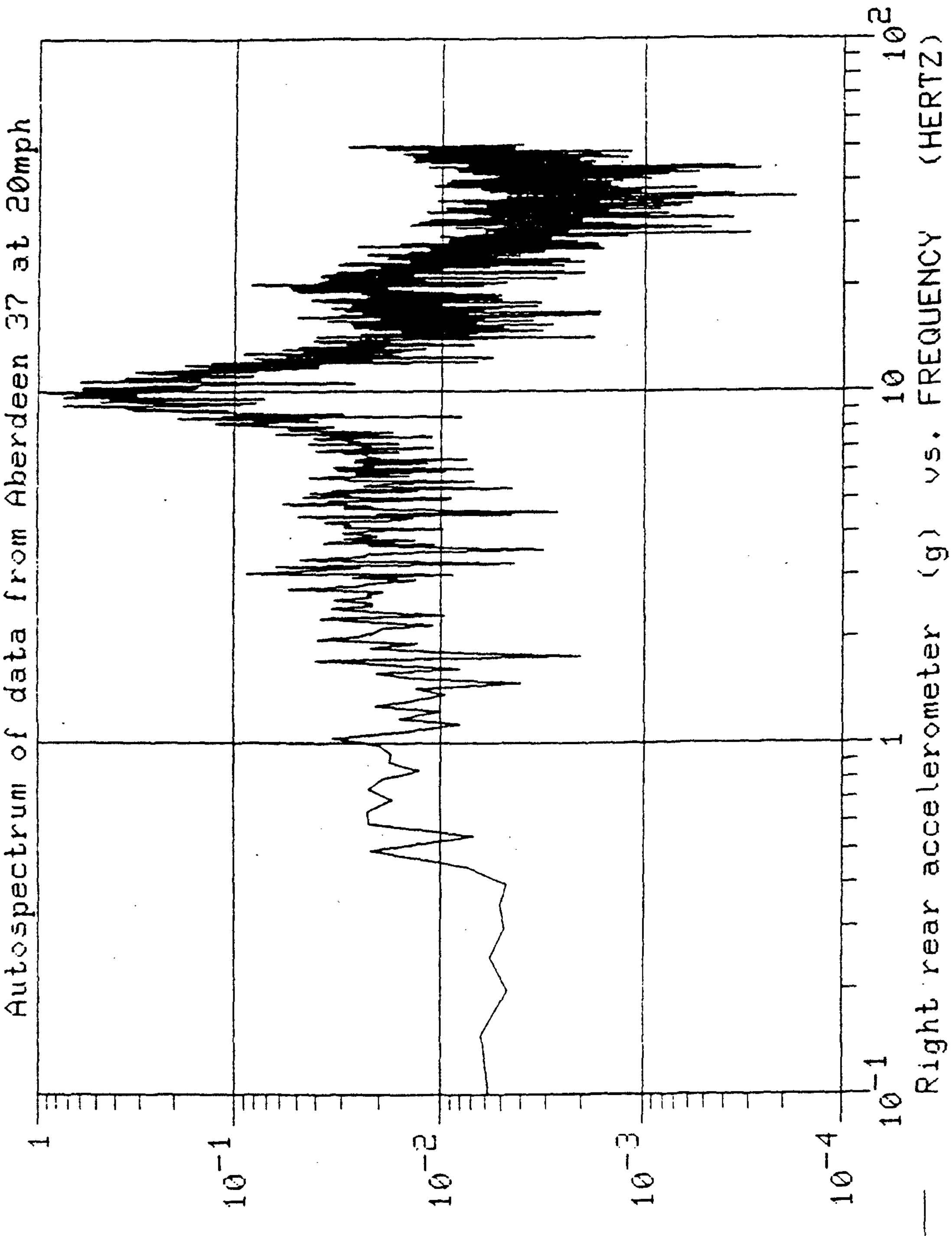

Autospectrum of data from Aberdeen 37 at 20mph
Right rear accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
1
10
10^{2}

Figure 5

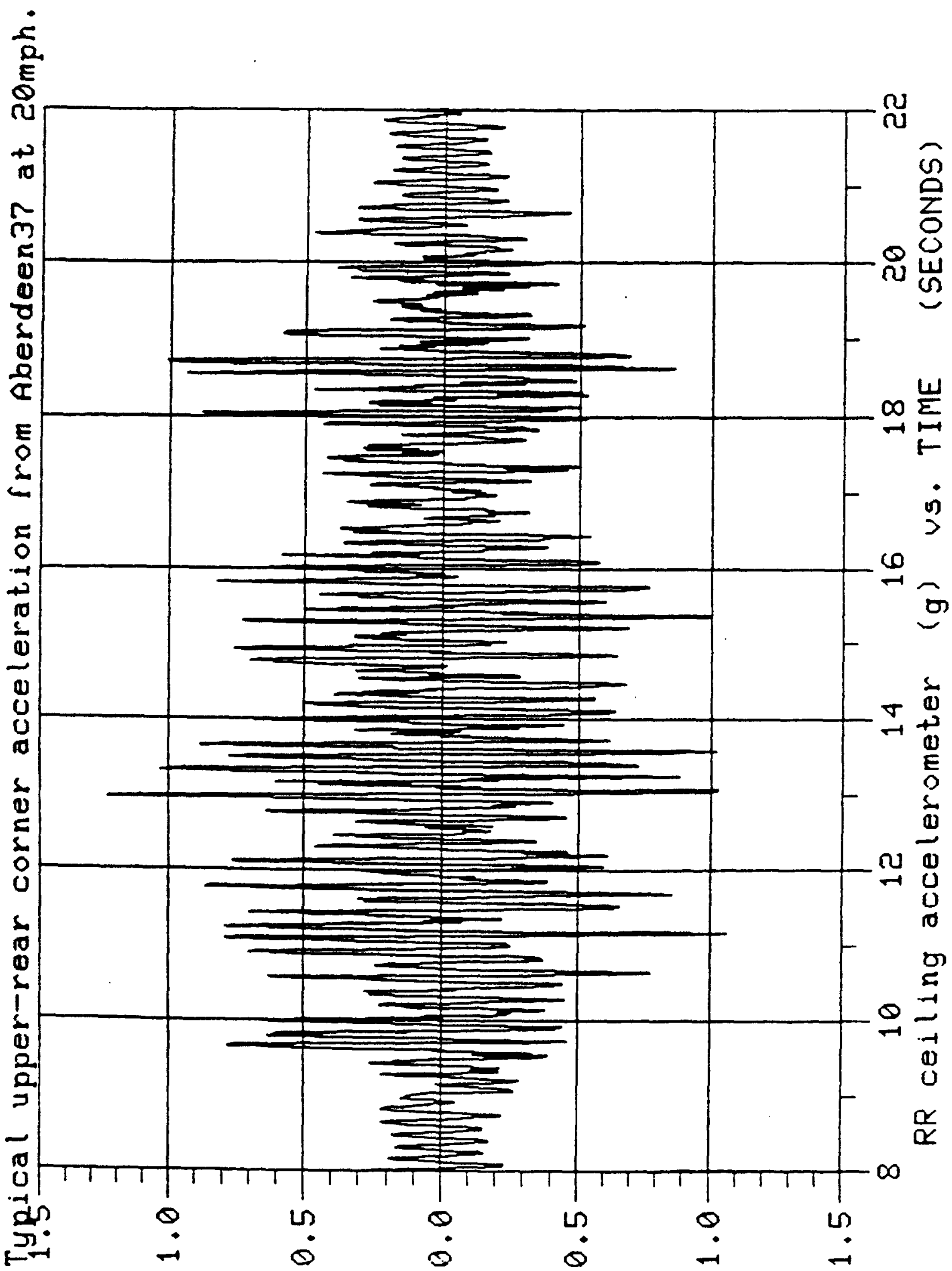

Typical upper-rear corner acceleration from Aberdeen37 at 20mph.
RR ceiling accelerometer (g) vs. TIME (SECONDS)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
8
10
12
14
16
18
20
22

Figure 6

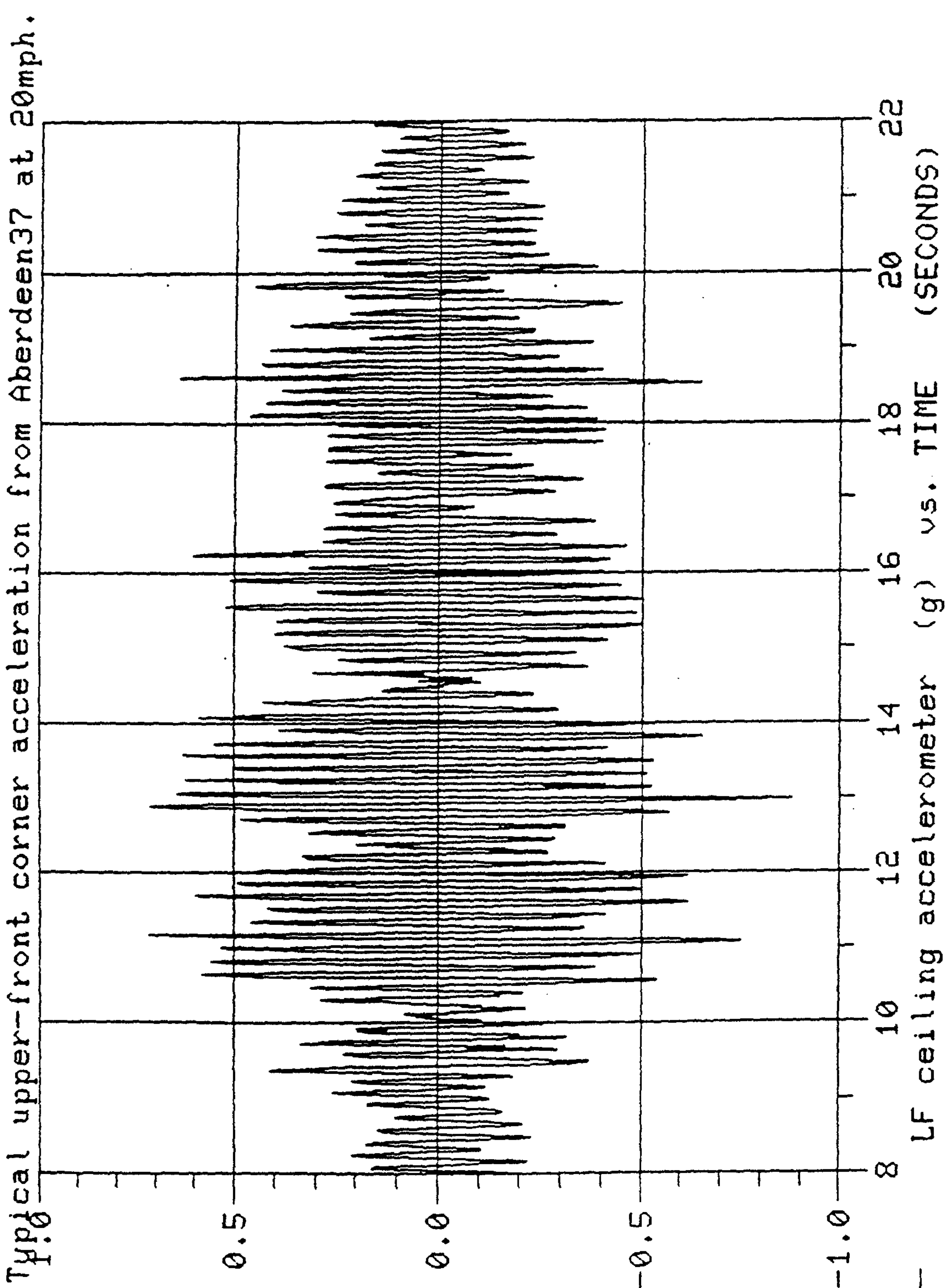

Typical upper-front corner acceleration from Aberdeen37 at 20mph.
1.0
0.5
0.0
-0.5
-1.0
8
10
12
14
16
18
20
22
LF ceiling accelerometer (g) vs. TIME (SECONDS)

Figure 7

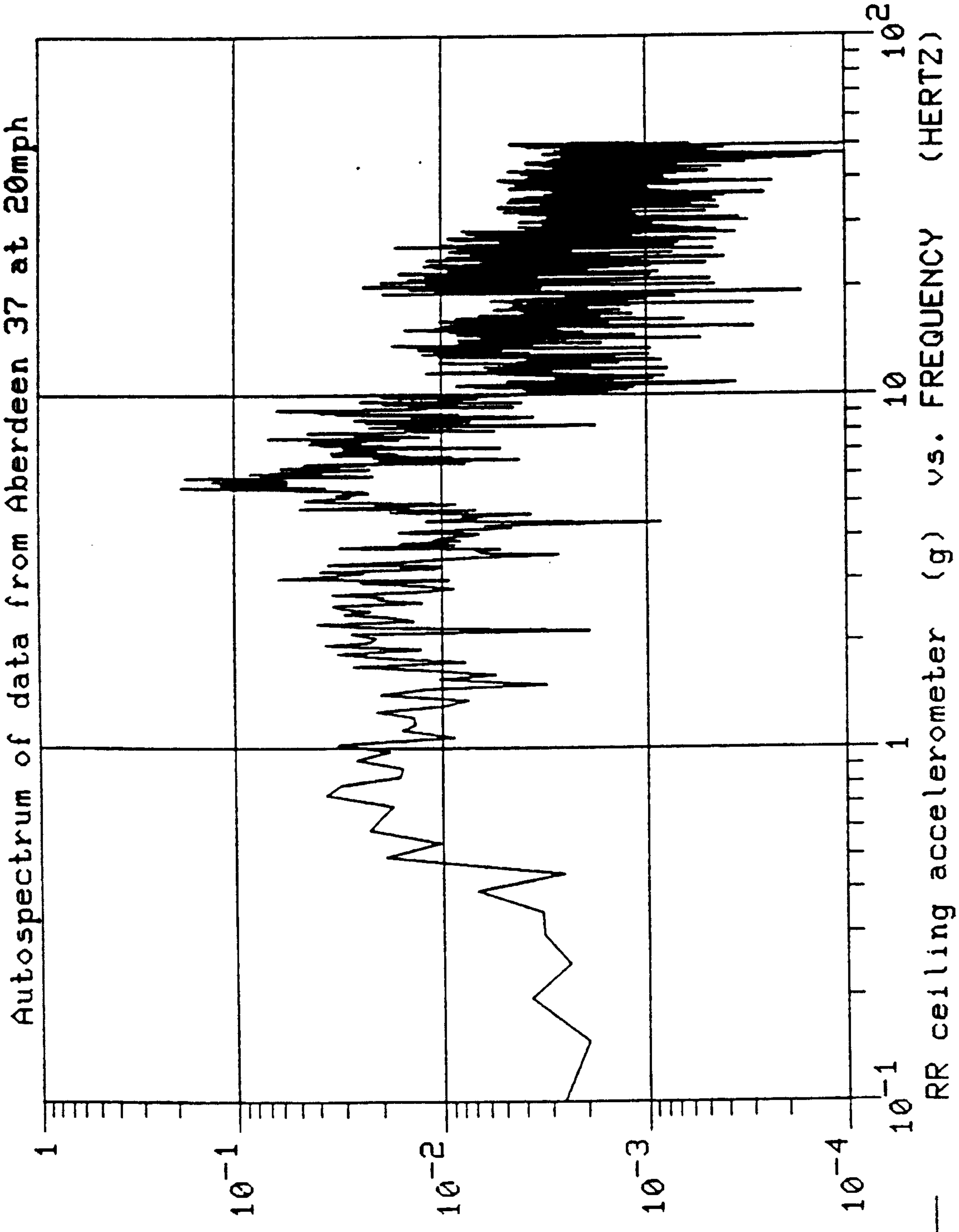

Autospectrum of data from Aberdeen 37 at 20mph
RR ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 8

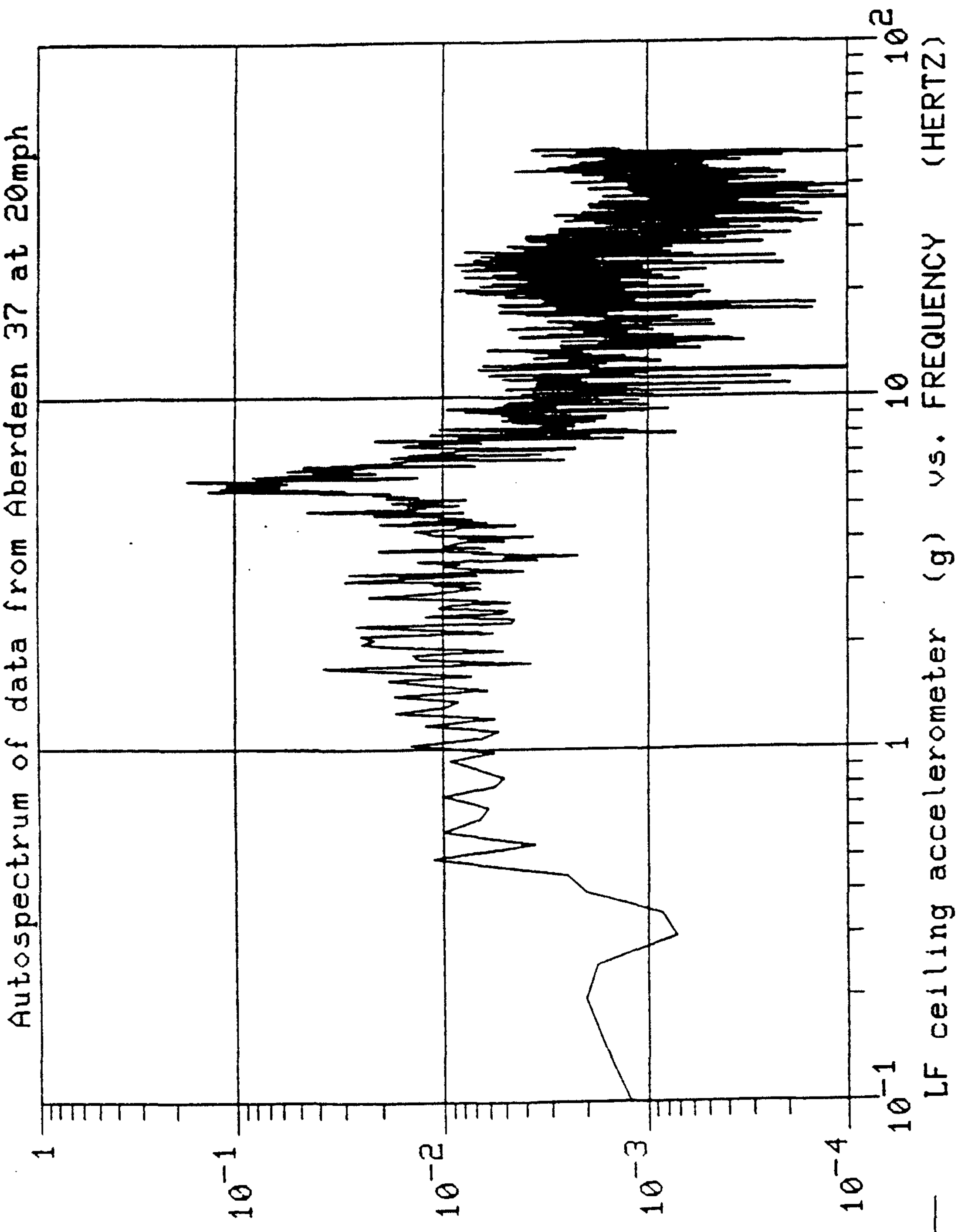

Autospectrum of data from Aberdeen 37 at 20mph
LF ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 9

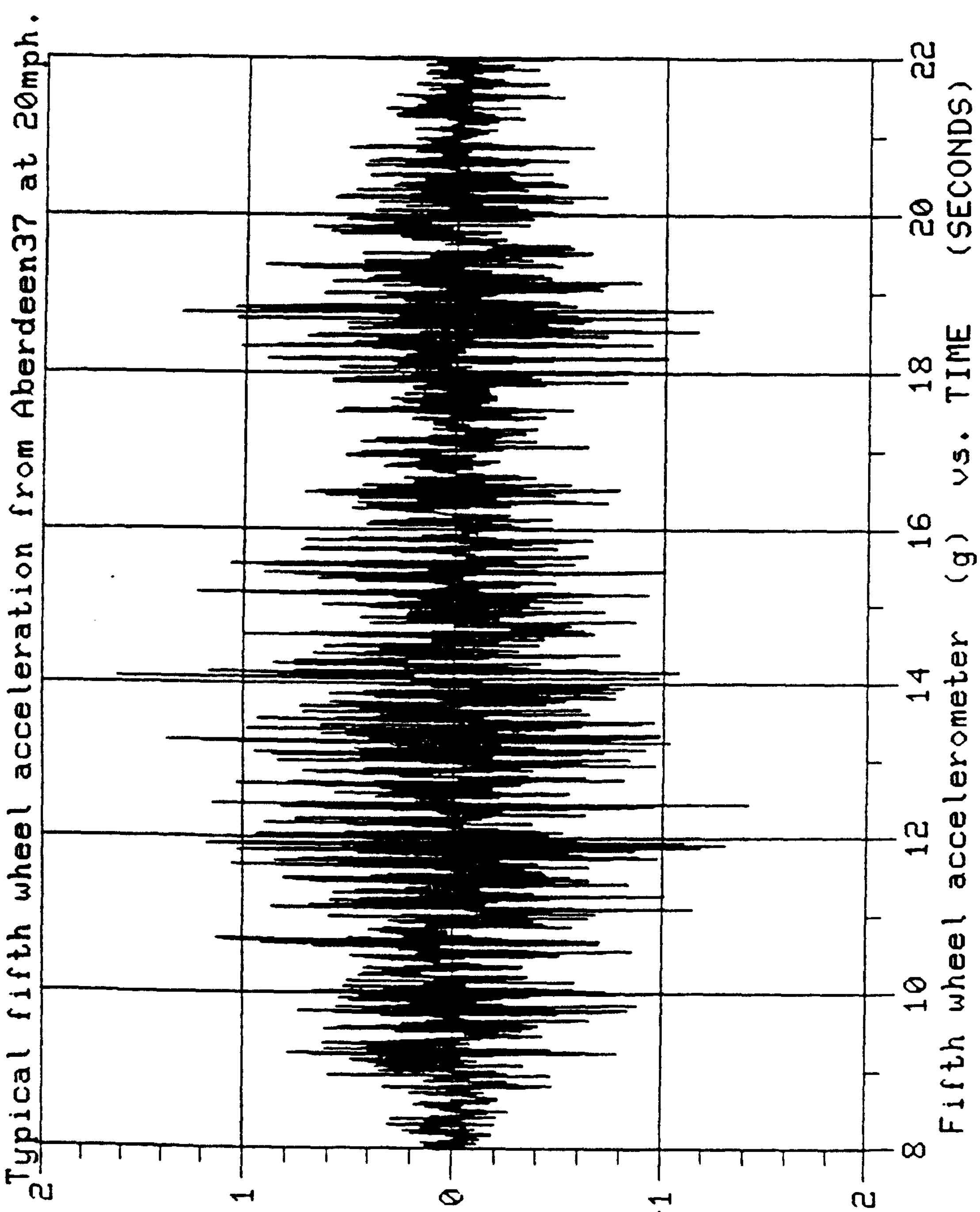

Typical fifth wheel acceleration from Aberdeen37 at 20mph.
Fifth wheel accelerometer (g) vs. TIME (SECONDS)
2
1
0
-1
-2
8
10
12
14
16
18
20
22

Figure 10

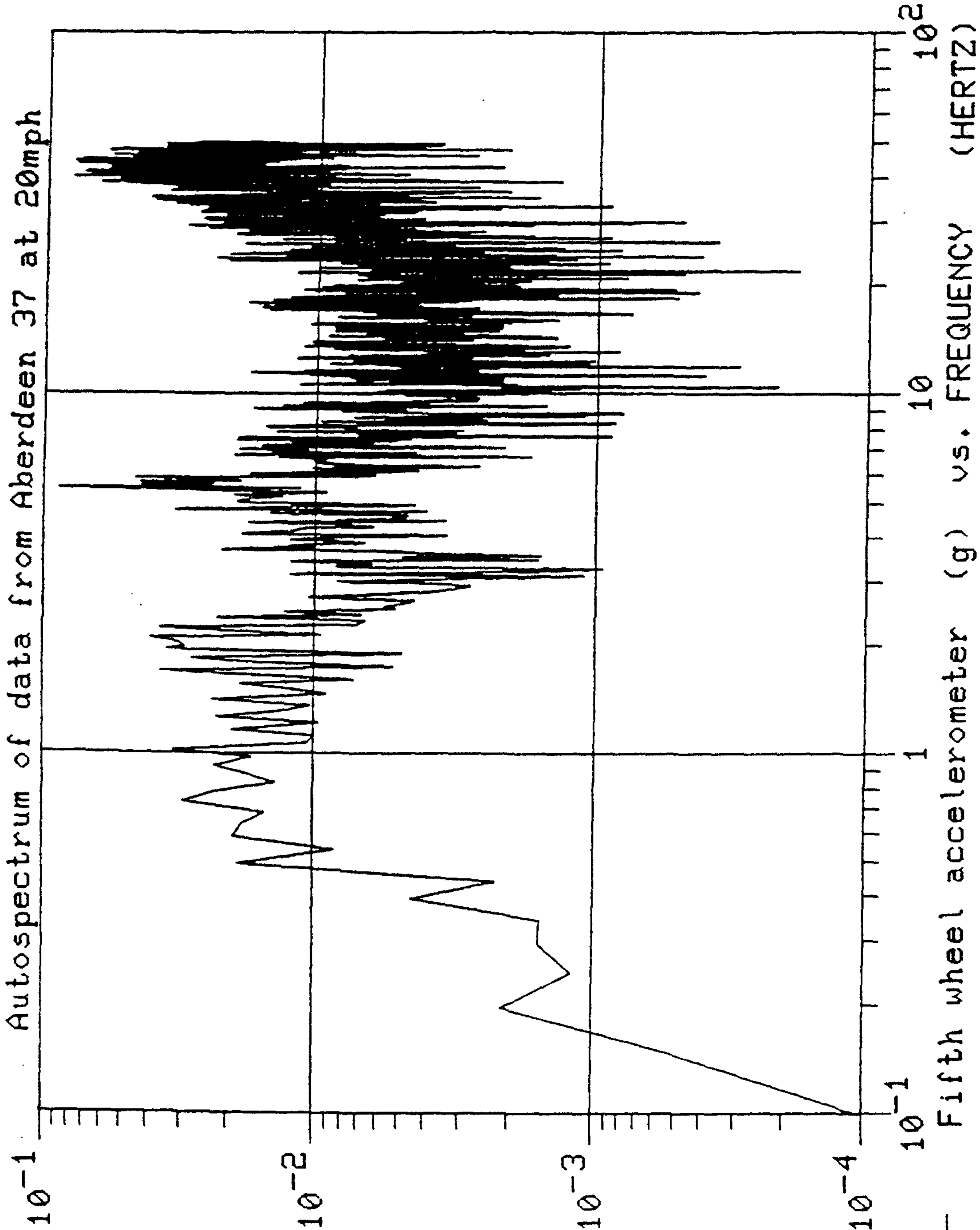

Autospectrum of data from Aberdeen 37 at 20mph
Fifth wheel accelerometer (g) vs. FREQUENCY (HERTZ)
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 11

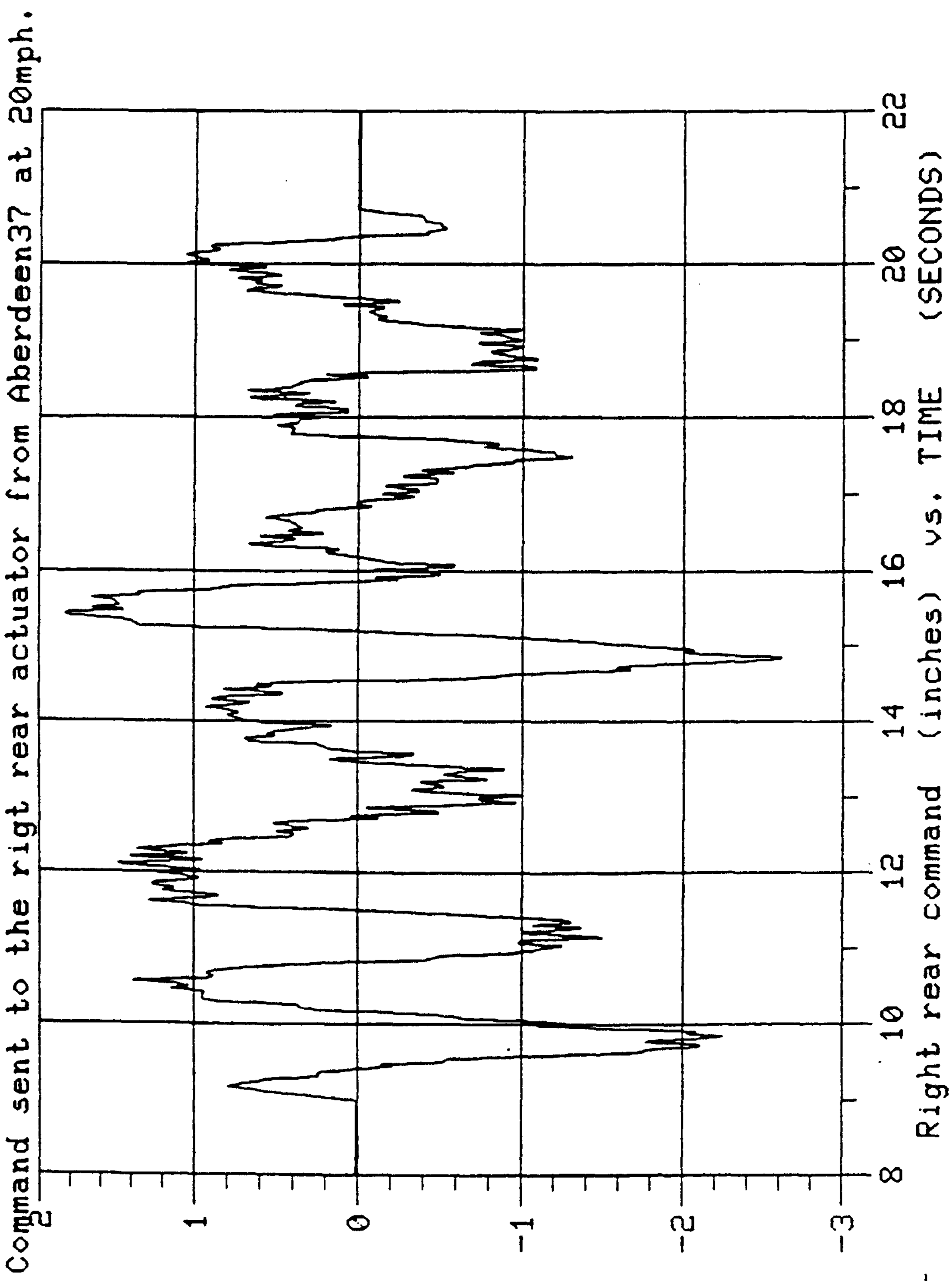
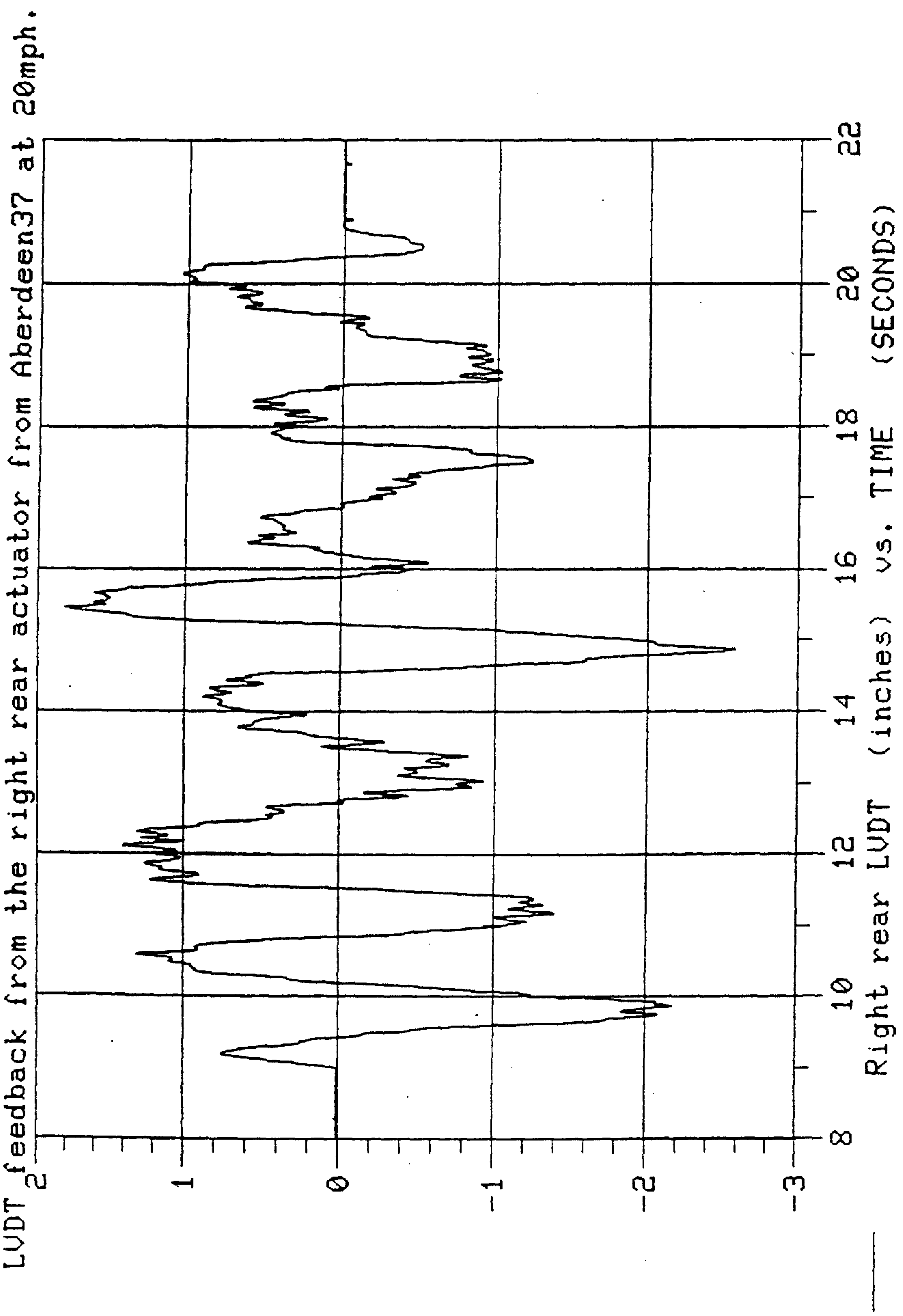

Command sent to the rigt rear actuator from Aberdeen37 at 20mph.
Right rear command (inches) vs. TIME (SECONDS)
2
1
0
-1
-2
-3
8
10
12
14
16
18
20
22

Figure 12



LVDT feedback from the right rear actuator from Aberdeen37 at 20mph.
Right rear LVDT (inches) vs. TIME (SECONDS)
2
1
0
-1
-2
-3
8
10
12
14
16
18
20
22

Figure 13

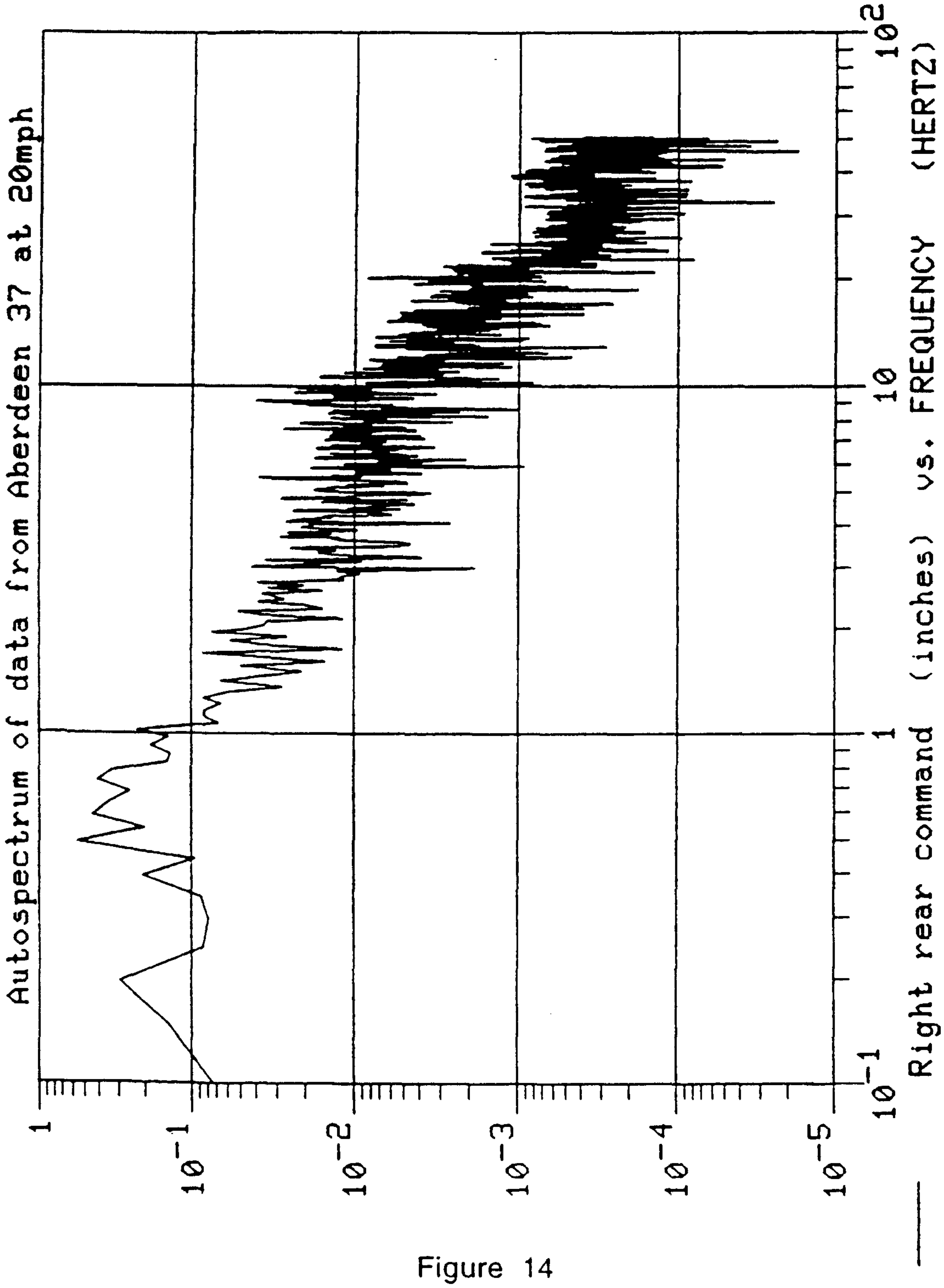

Autospectrum of data from Aberdeen 37 at 20mph
Right rear command (inches) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10
10^2

Figure 14

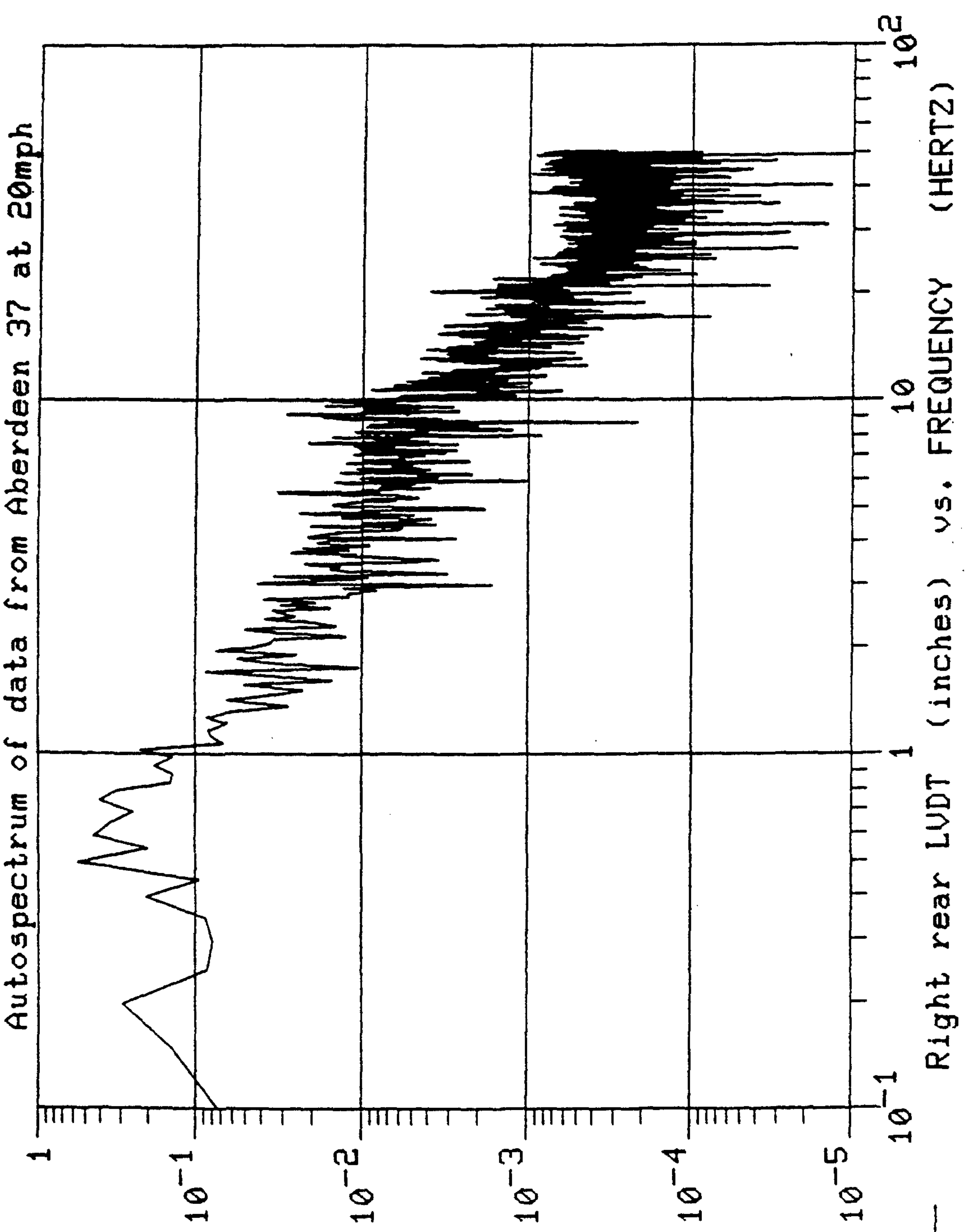
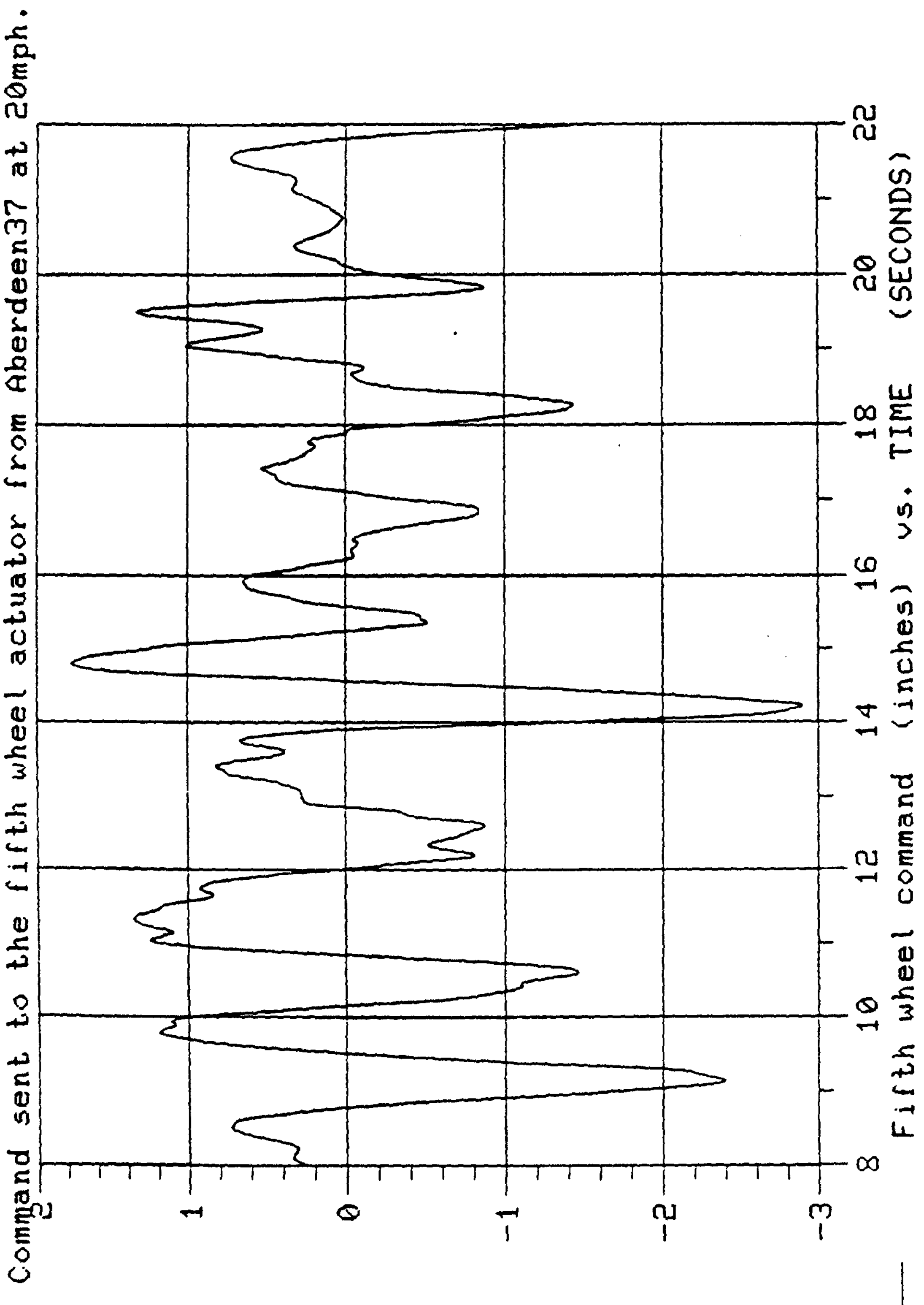

Autospectrum of data from Aberdeen 37 at 20mph
Right rear LVDT (inches) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10
10^2

Figure 15



Command sent to the fifth wheel actuator from Aberdeen37 at 20mph.
Fifth wheel command (inches) vs. TIME (SECONDS)
2
1
0
-1
-2
-3
8
10
12
14
16
18
20
22

Figure 16

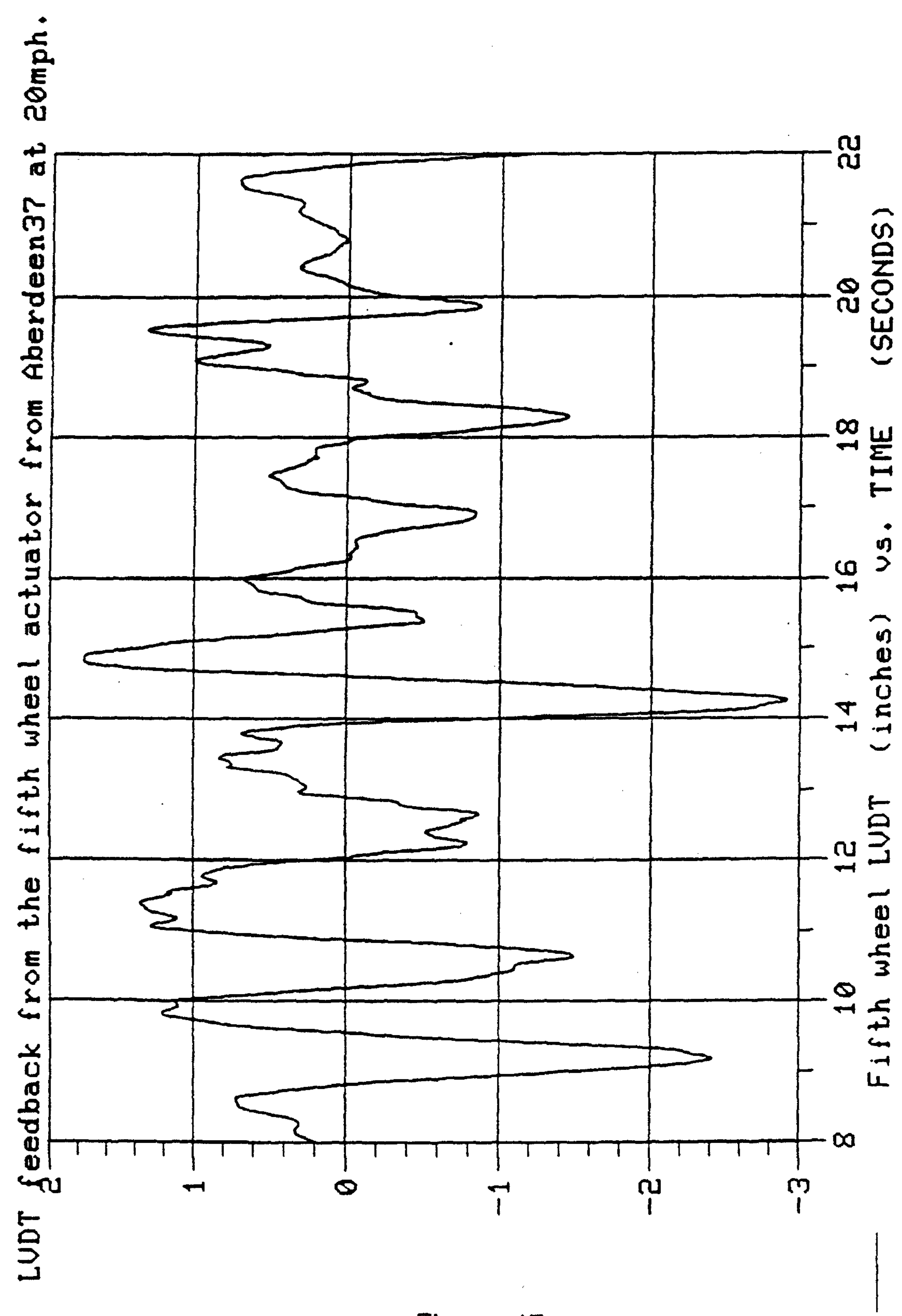
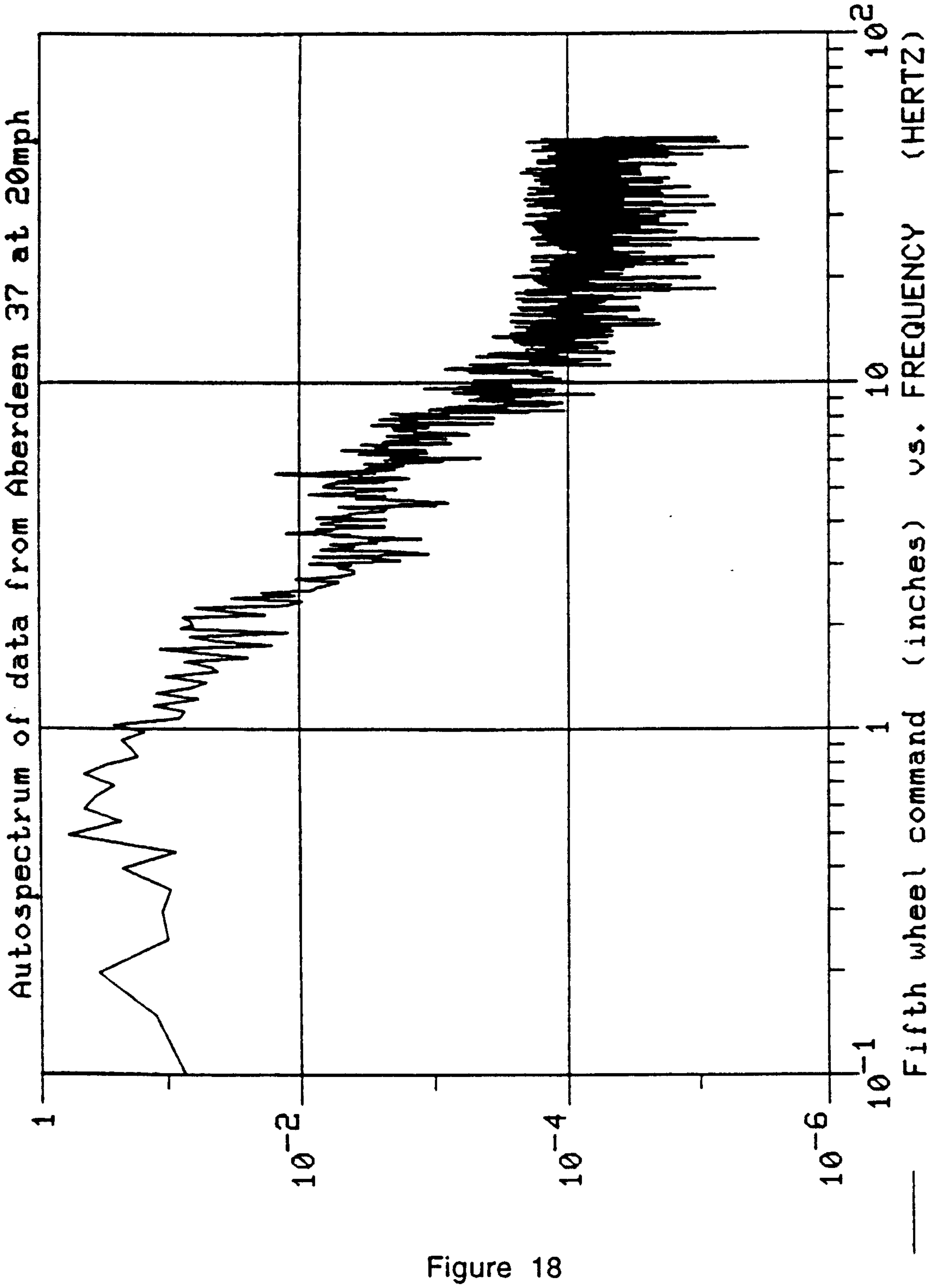
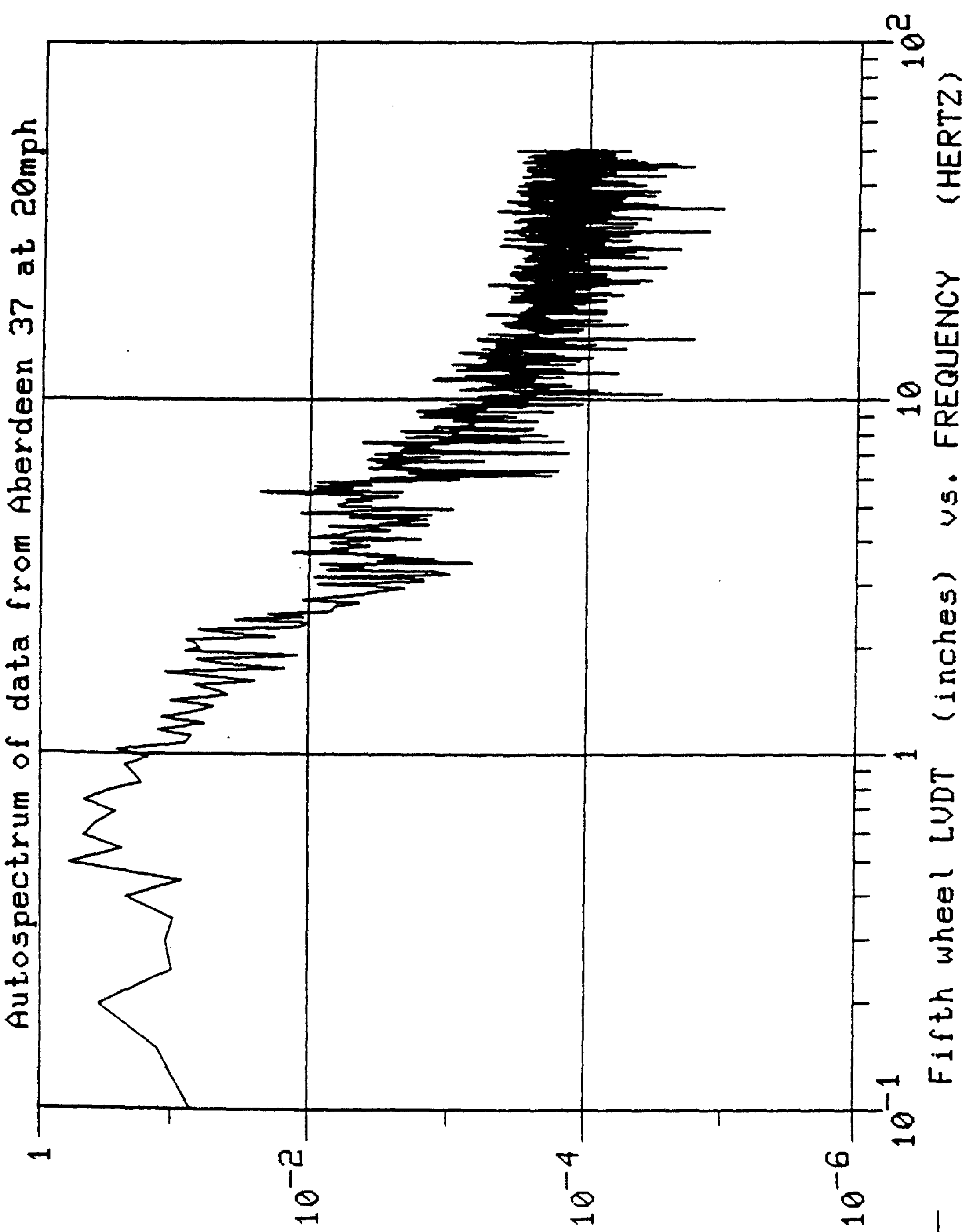

LVDT feedback from the fifth wheel actuator from Aberdeen37 at 20mph.
Fifth wheel LVDT (inches) vs. TIME (SECONDS)
2
1
0
-1
-2
-3
8
10
12
14
16
18
20
22

Figure 17



Autospectrum of data from Aberdeen 37 at 20mph
Fifth wheel command (inches) vs. FREQUENCY (HERTZ)
1
10^{-2}
10^{-4}
10^{-6}
10^{-1}
1
10
10^{2}

Figure 18



Autospectrum of data from Aberdeen 37 at 20mph
Fifth wheel LVDT (inches) vs. FREQUENCY (HERTZ)
1
10^{-2}
10^{-4}
10^{-6}
10^{-1}
1
10
10^{2}

Figure 19

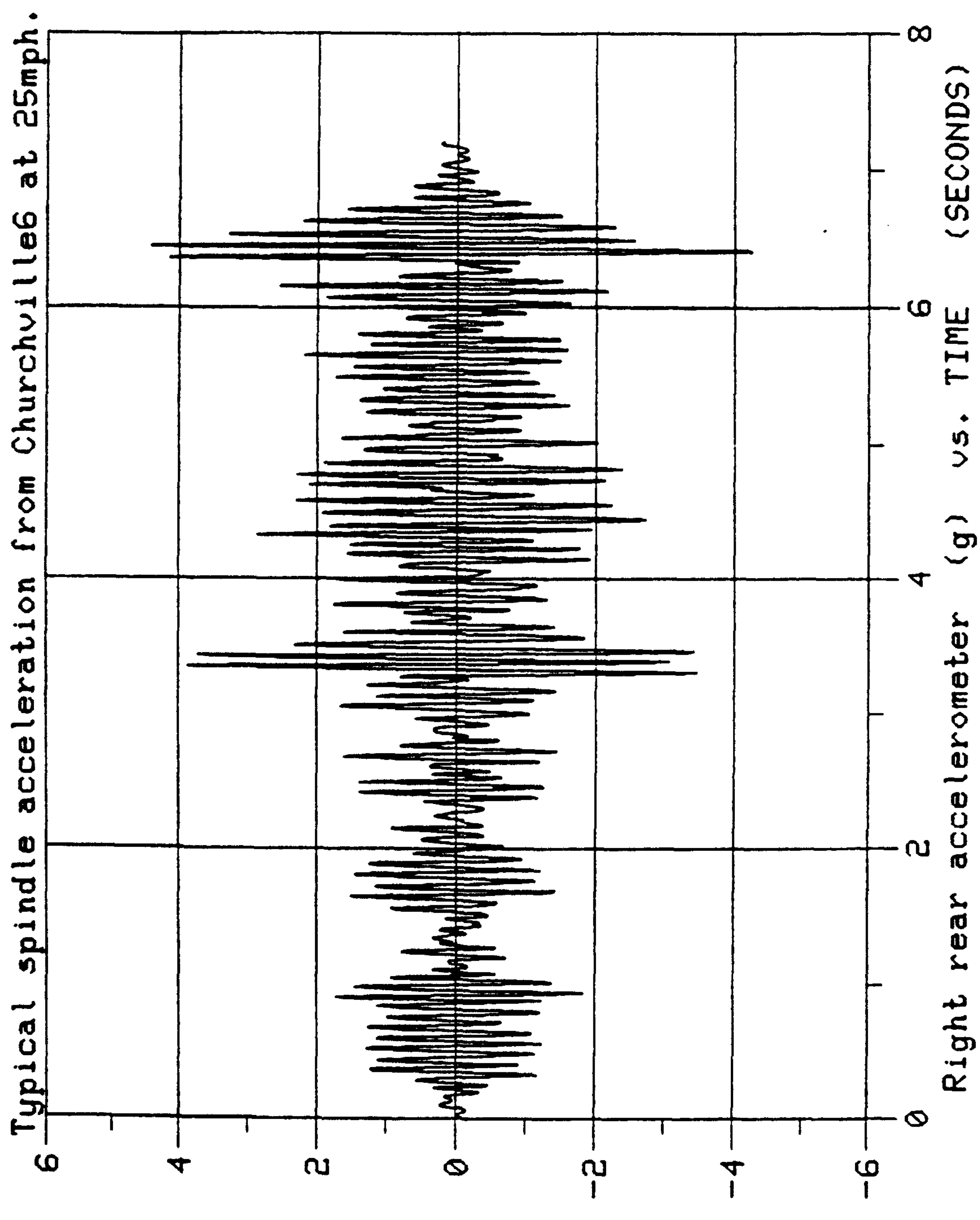

Typical spindle acceleration from Churchville6 at 25mph.
6
4
2
0
-2
-4
-6
0
2
4
6
8
Right rear accelerometer (g) vs. TIME (SECONDS)

Figure 20

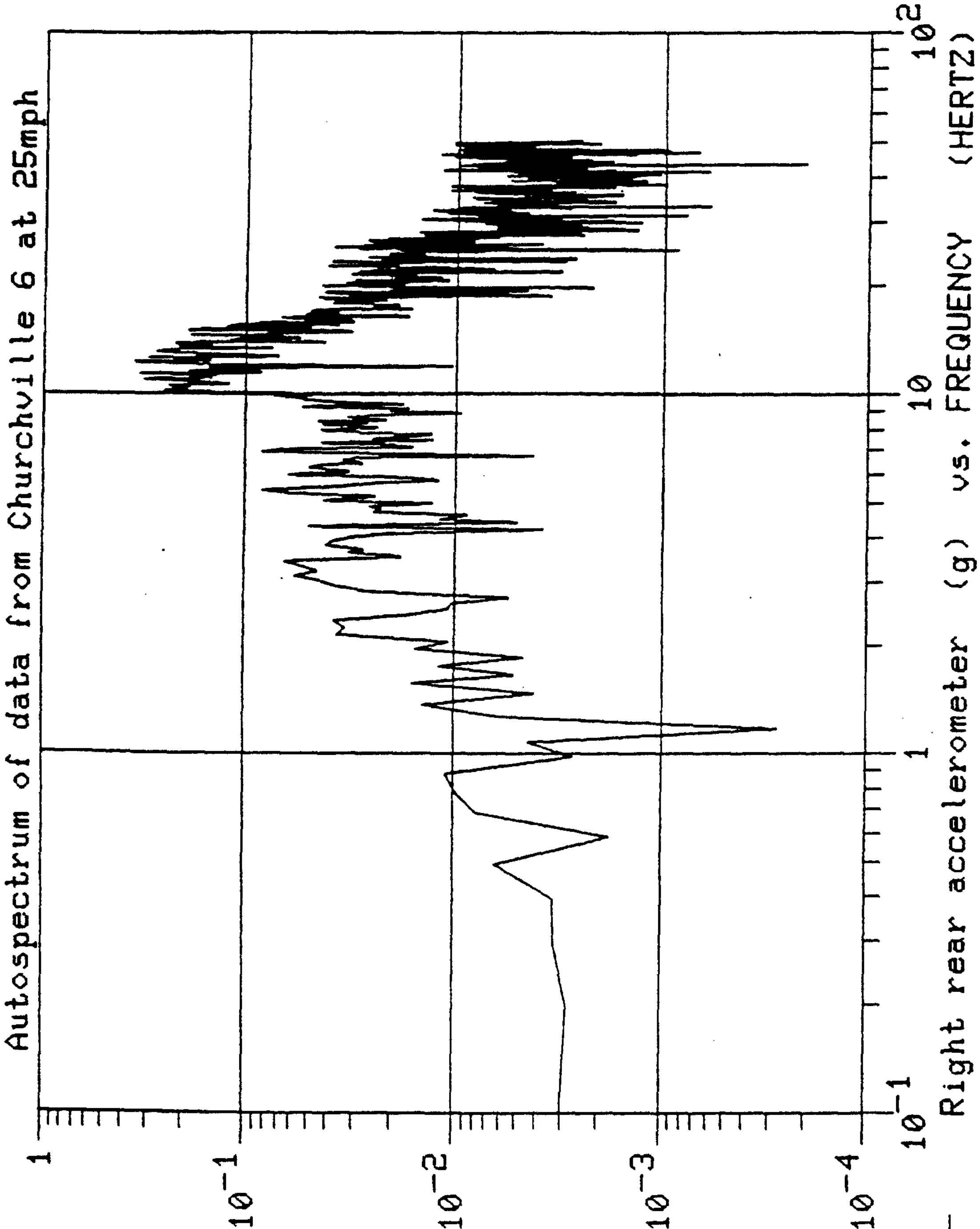

Autospectrum of data from Churchville 6 at 25mph
Right rear accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 21

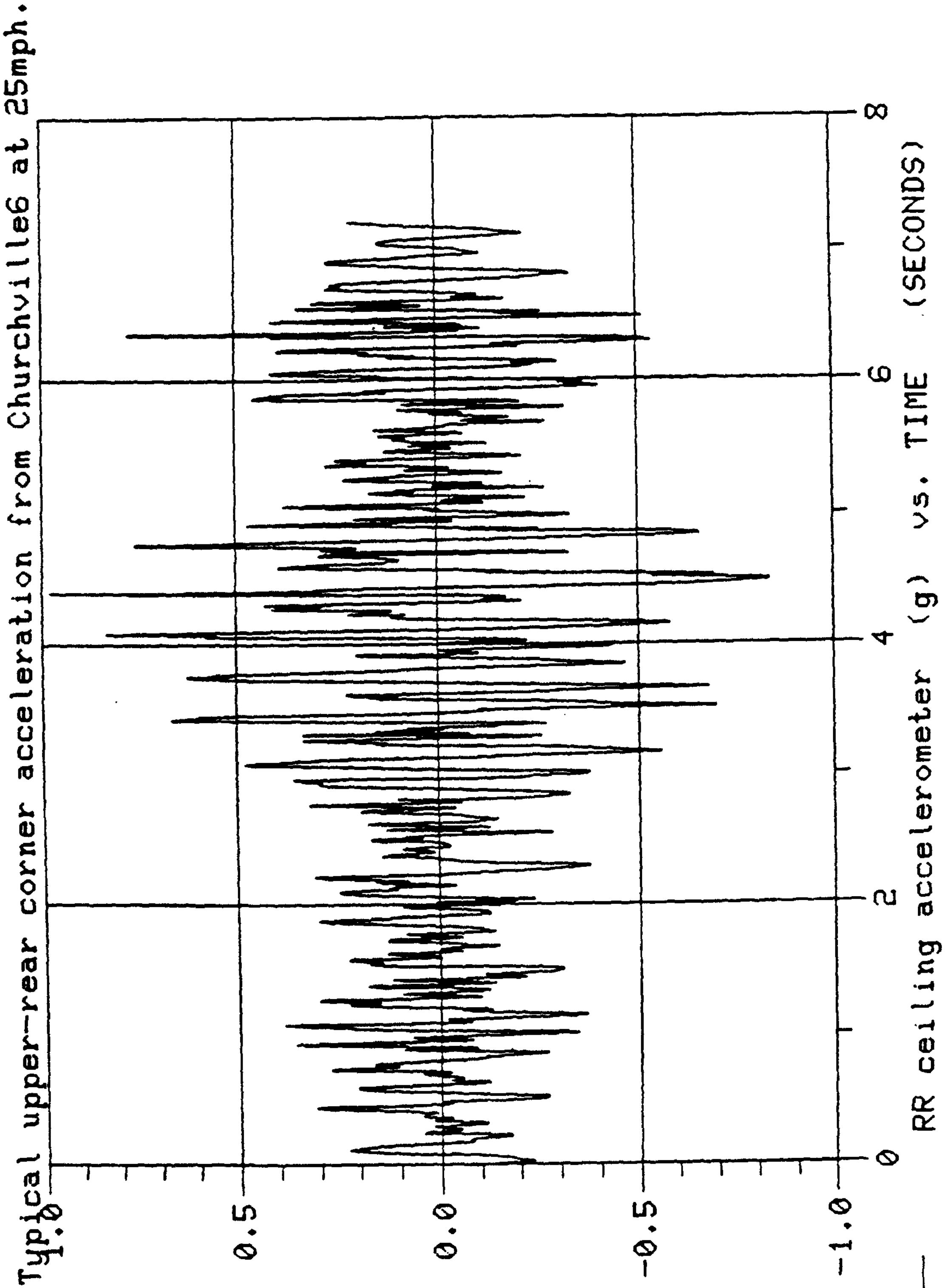

Typical upper-rear corner acceleration from Churchville6 at 25mph.
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8
RR ceiling accelerometer (g) vs. TIME (SECONDS)

Figure 22

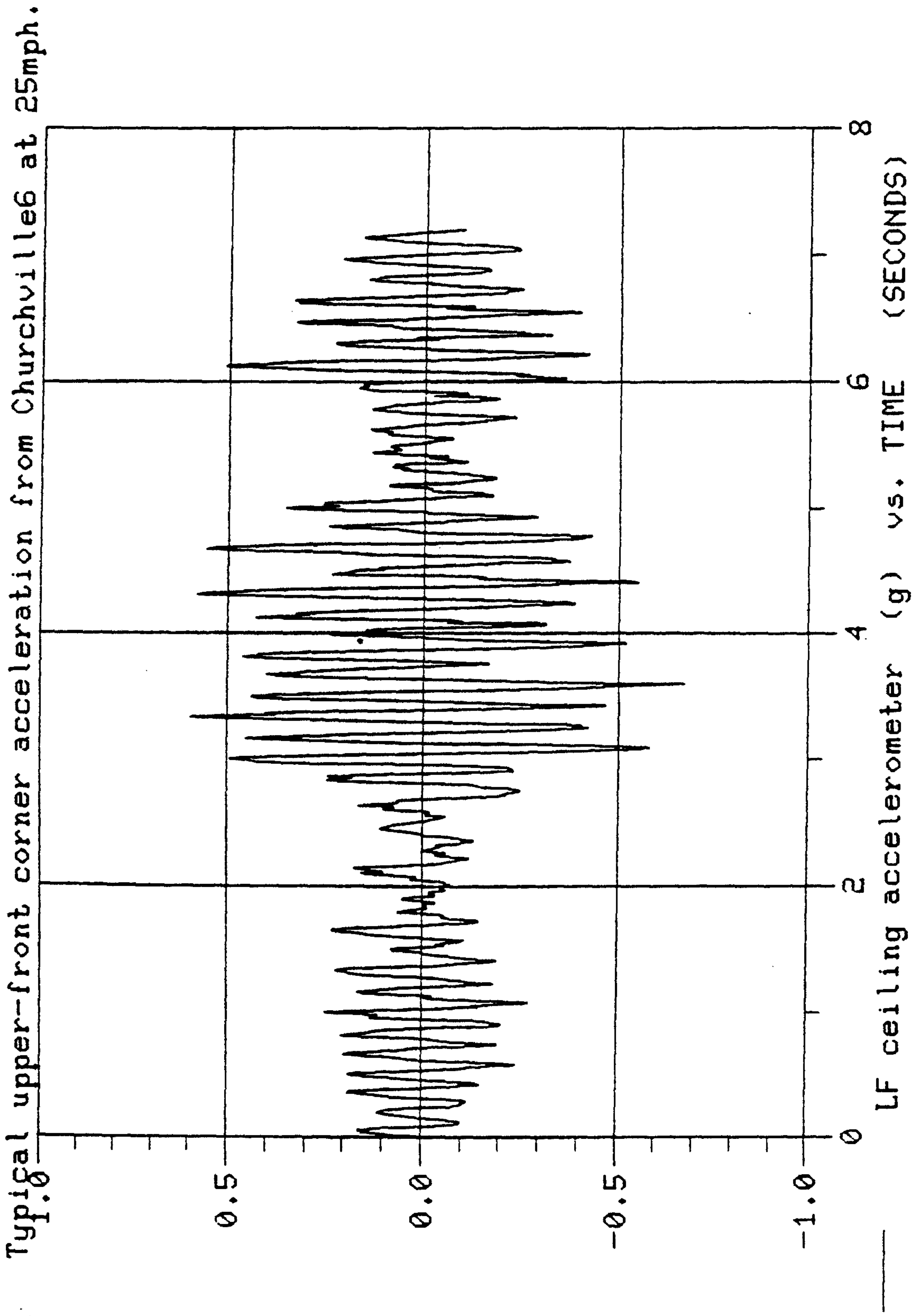

Typical upper-front corner acceleration from Churchville6 at 25mph.
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8
LF ceiling accelerometer (g) vs. TIME (SECONDS)

Figure 23

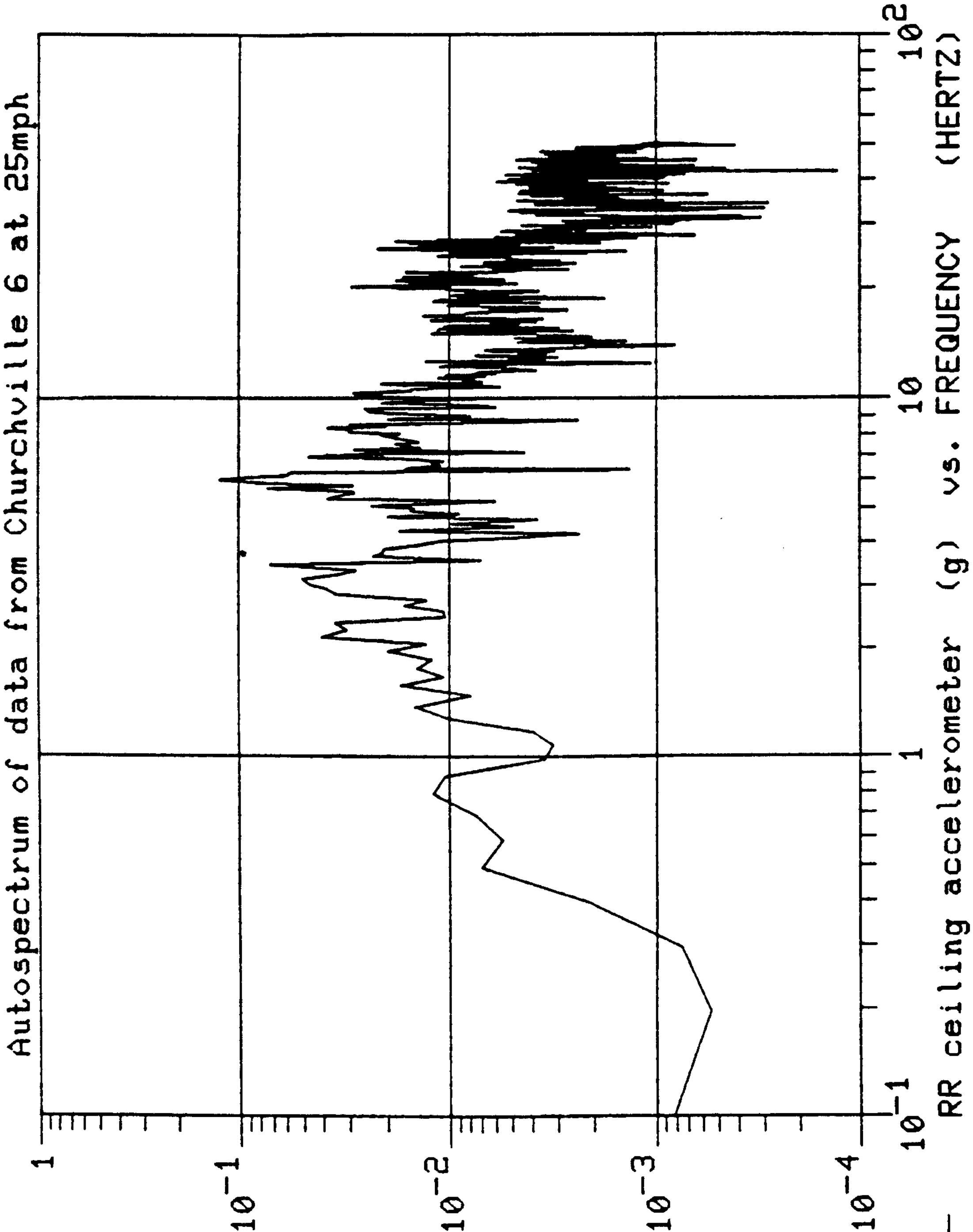

Autospectrum of data from Churchville 6 at 25mph
RR ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 24

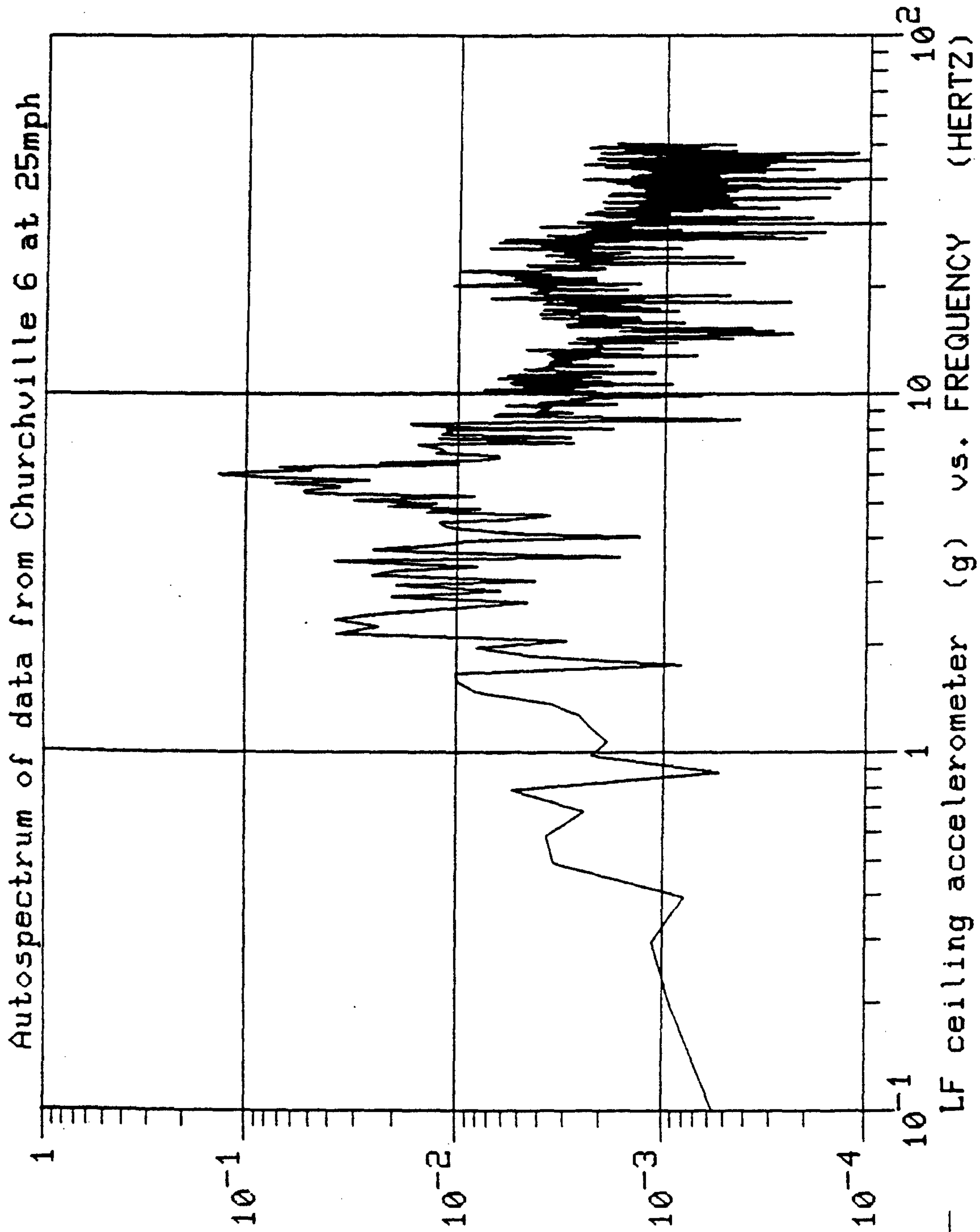

Autospectrum of data from Churchville 6 at 25mph
LF ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 25

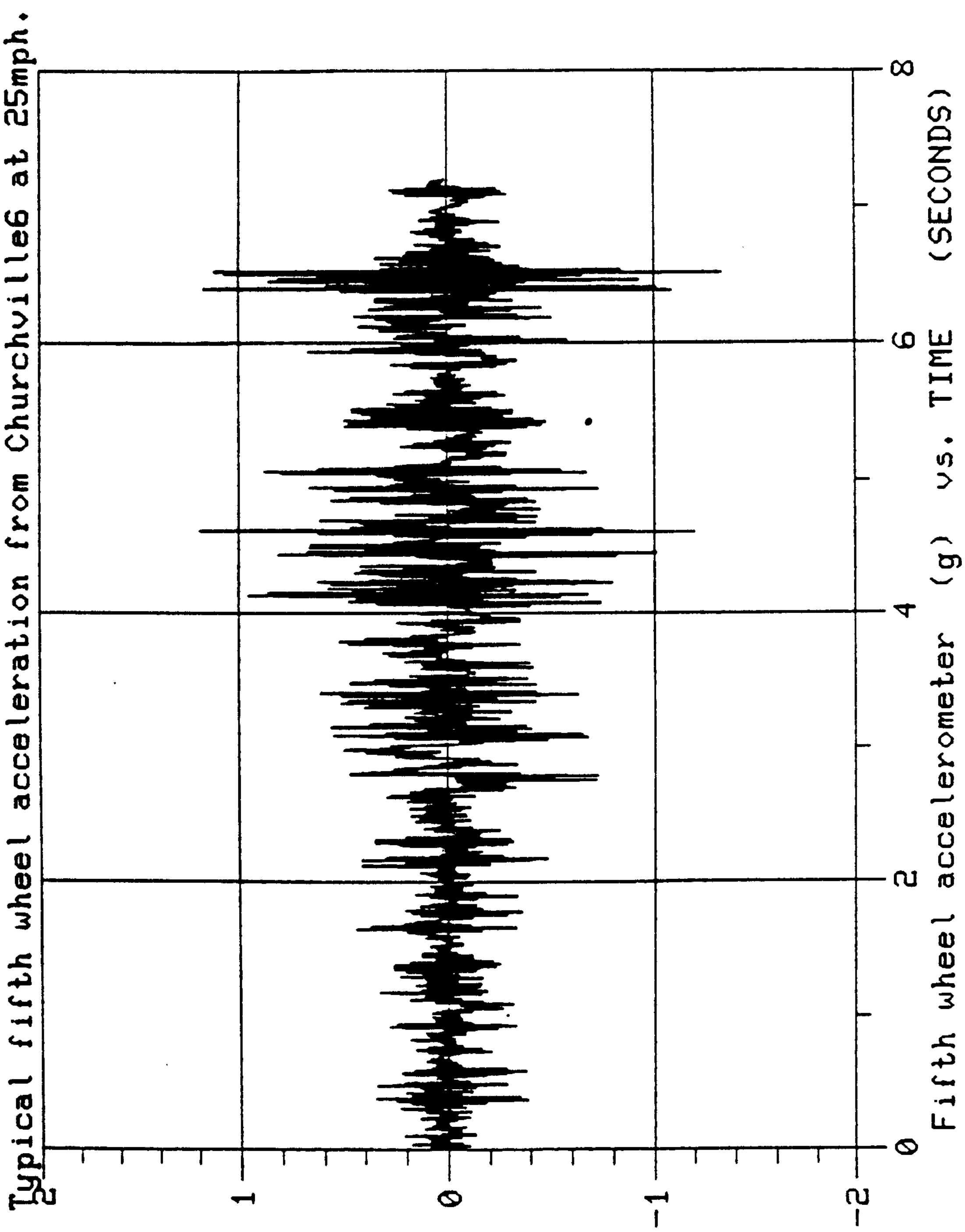

Typical fifth wheel acceleration from Churchville6 at 25mph.
Fifth wheel accelerometer (g) vs. TIME (SECONDS)
2
1
0
-1
-2
0
2
4
6
8

Figure 26

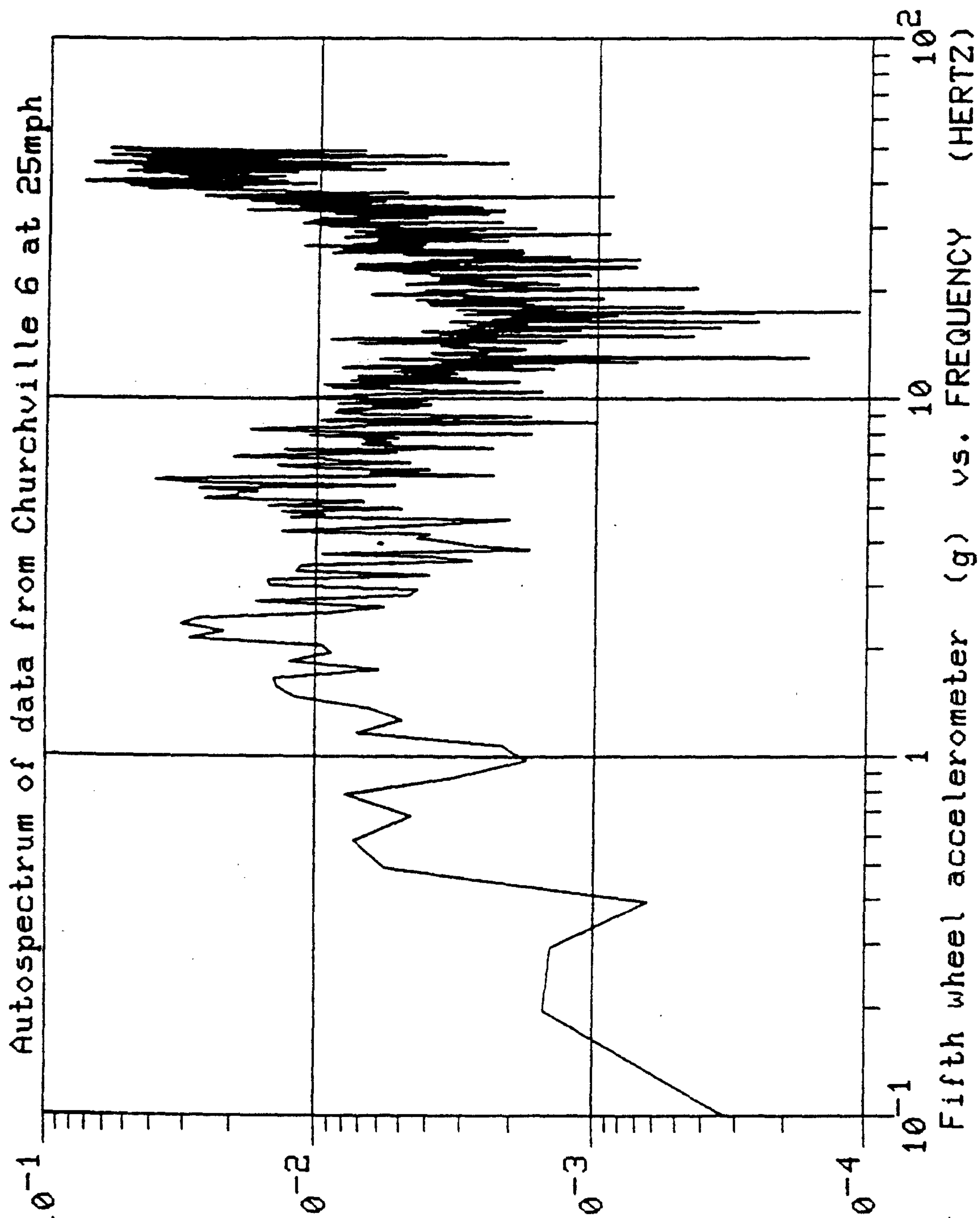

Autospectrum of data from Churchville 6 at 25mph
Fifth wheel accelerometer (g) vs. FREQUENCY (HERTZ)
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 27

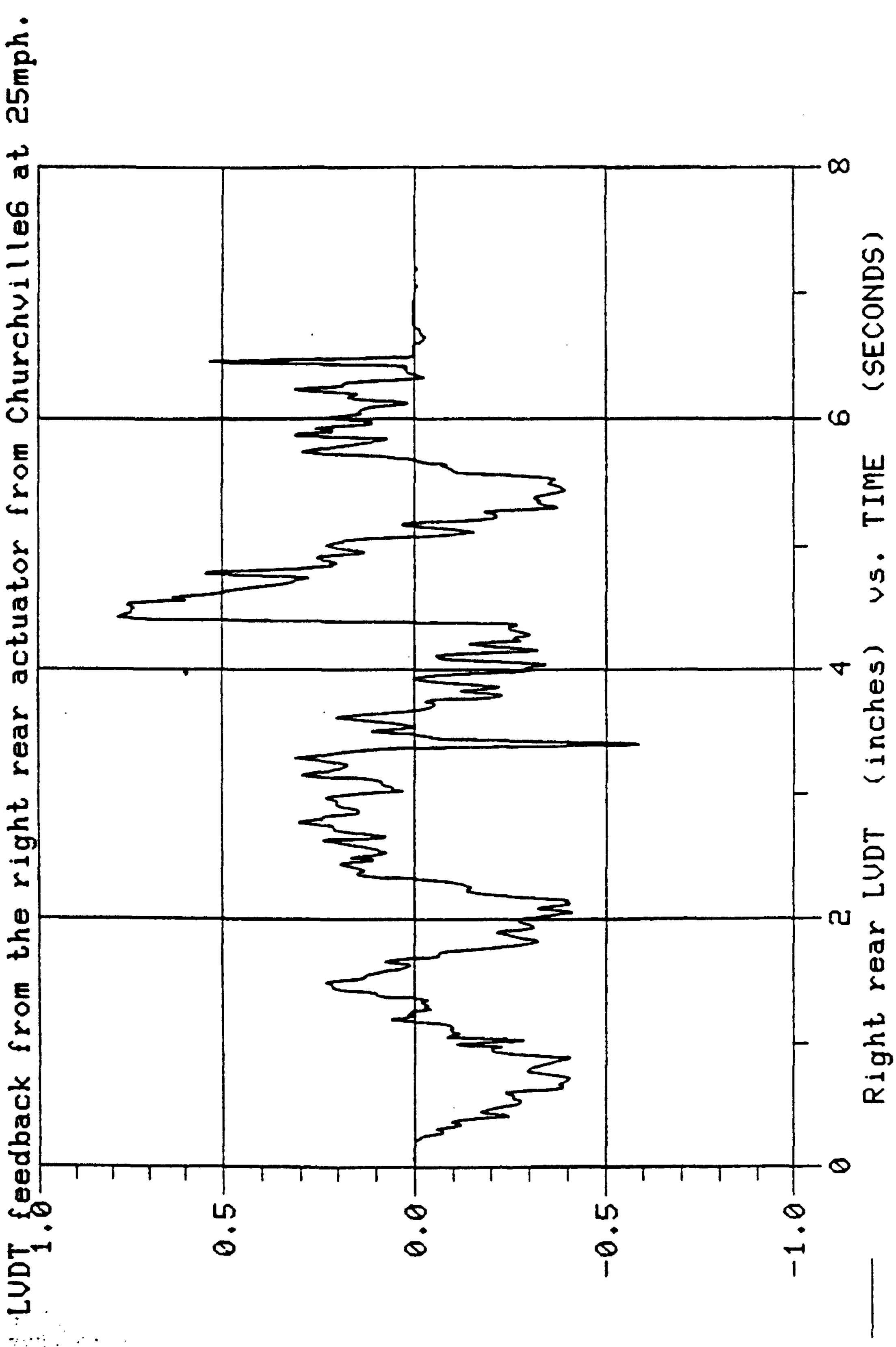
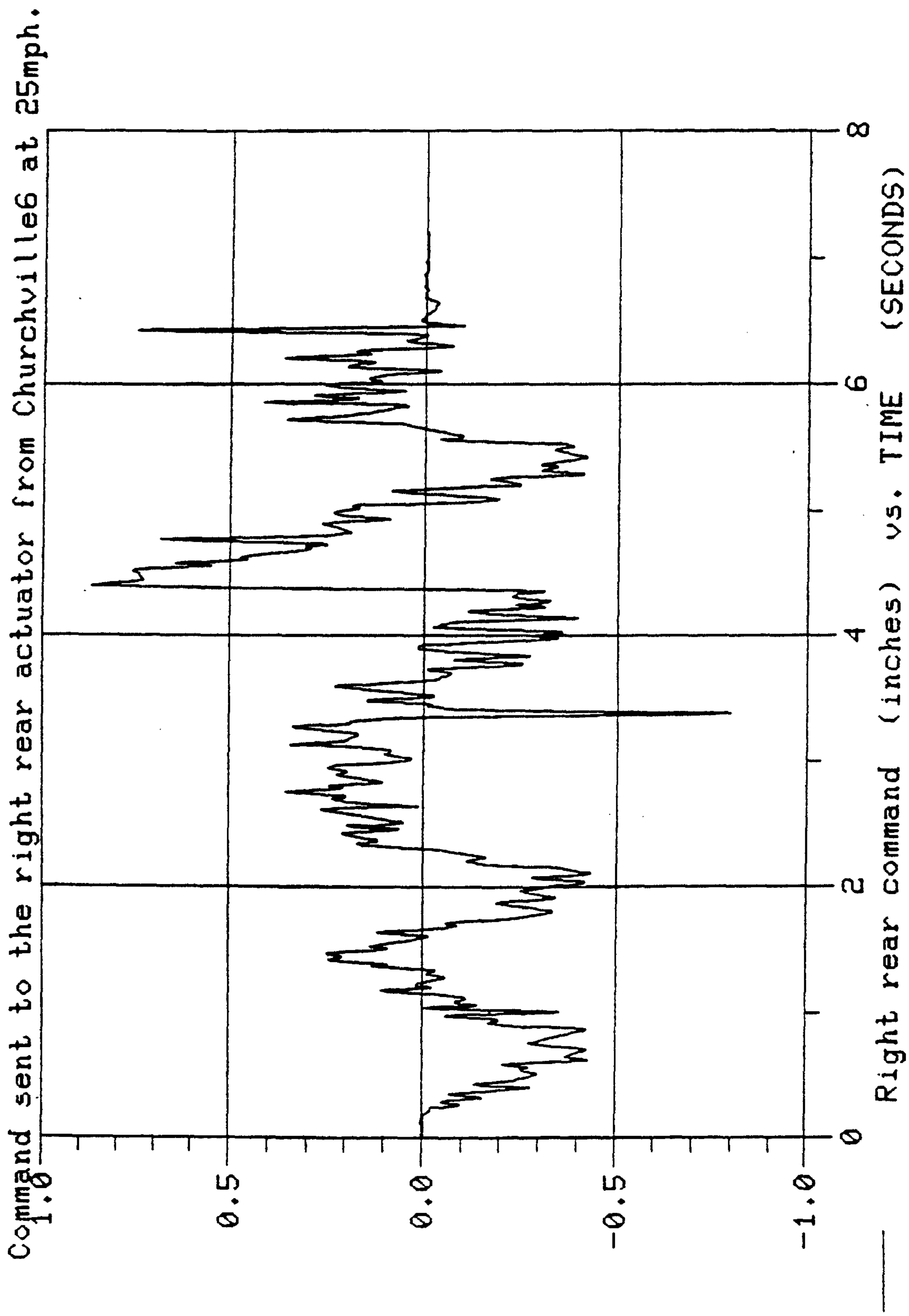

LVDT feedback from the right rear actuator from Churchville6 at 25mph.
Right rear LVDT (inches) vs. TIME (SECONDS)
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8

Figure 28



Command sent to the right rear actuator from Churchville6 at 25mph.
Right rear command (inches) vs. TIME (SECONDS)
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8

Figure 29

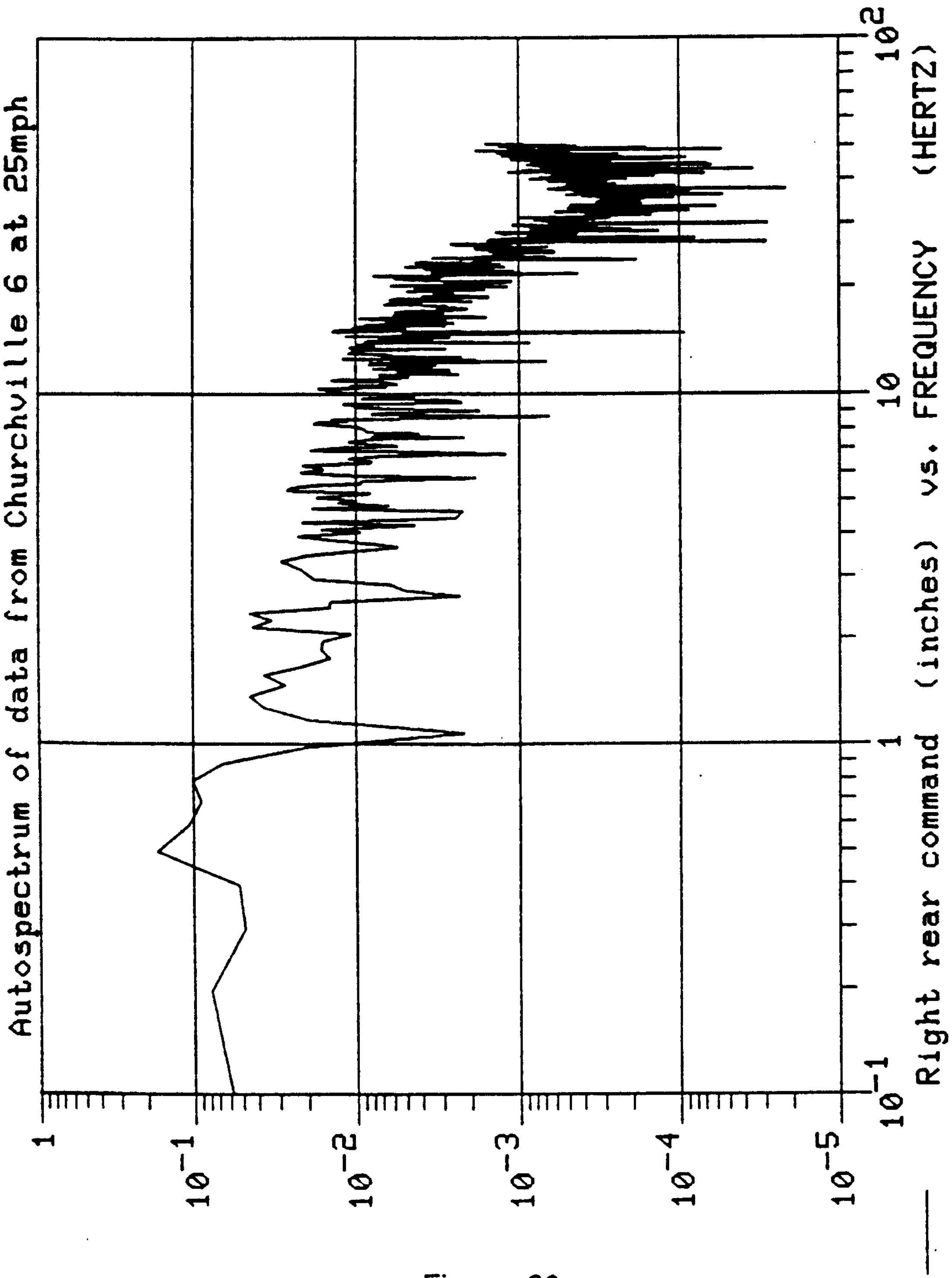

Autospectrum of data from Churchville 6 at 25mph
Right rear command (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 30

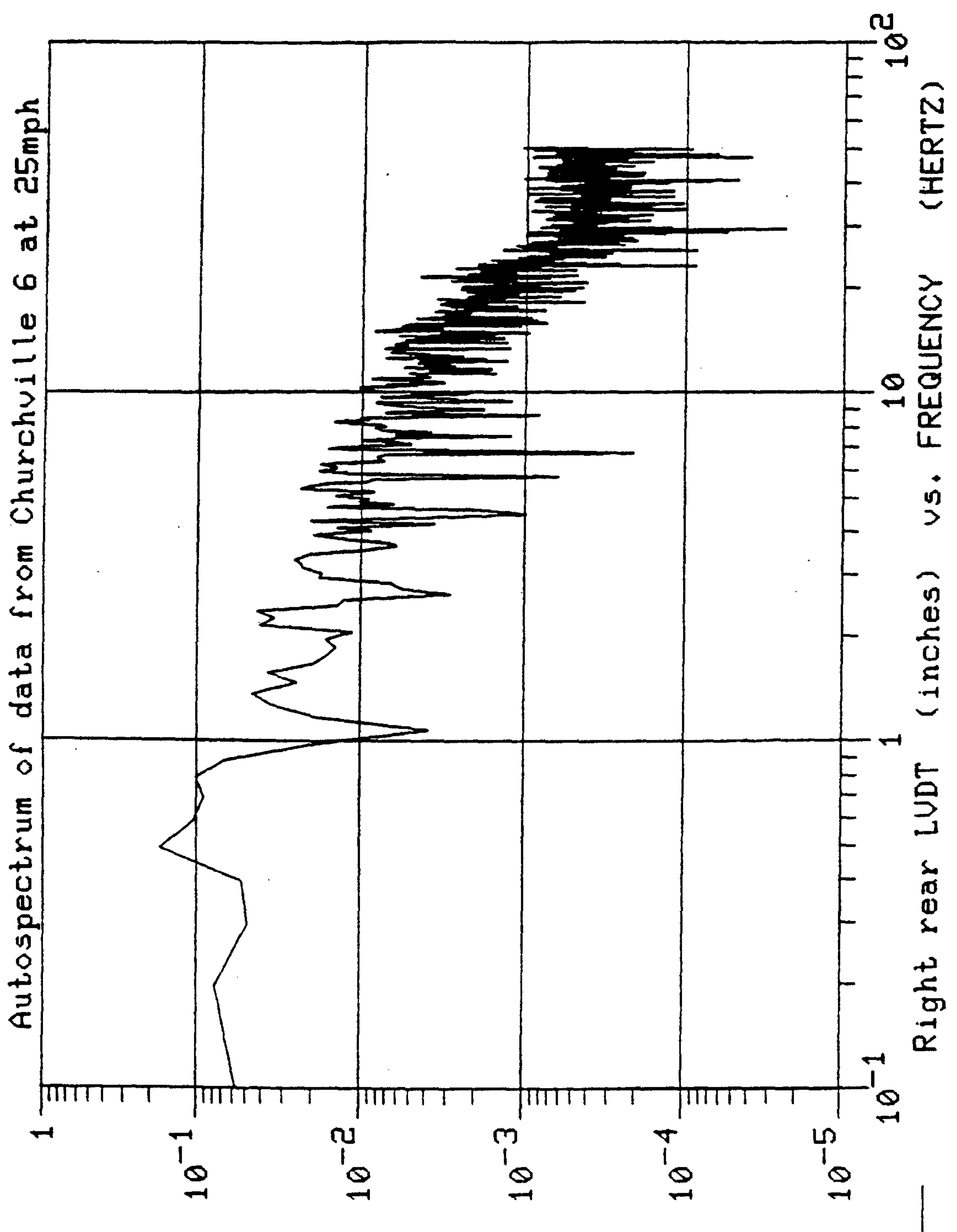

Autospectrum of data from Churchville 6 at 25mph
Right rear LVDT (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 31

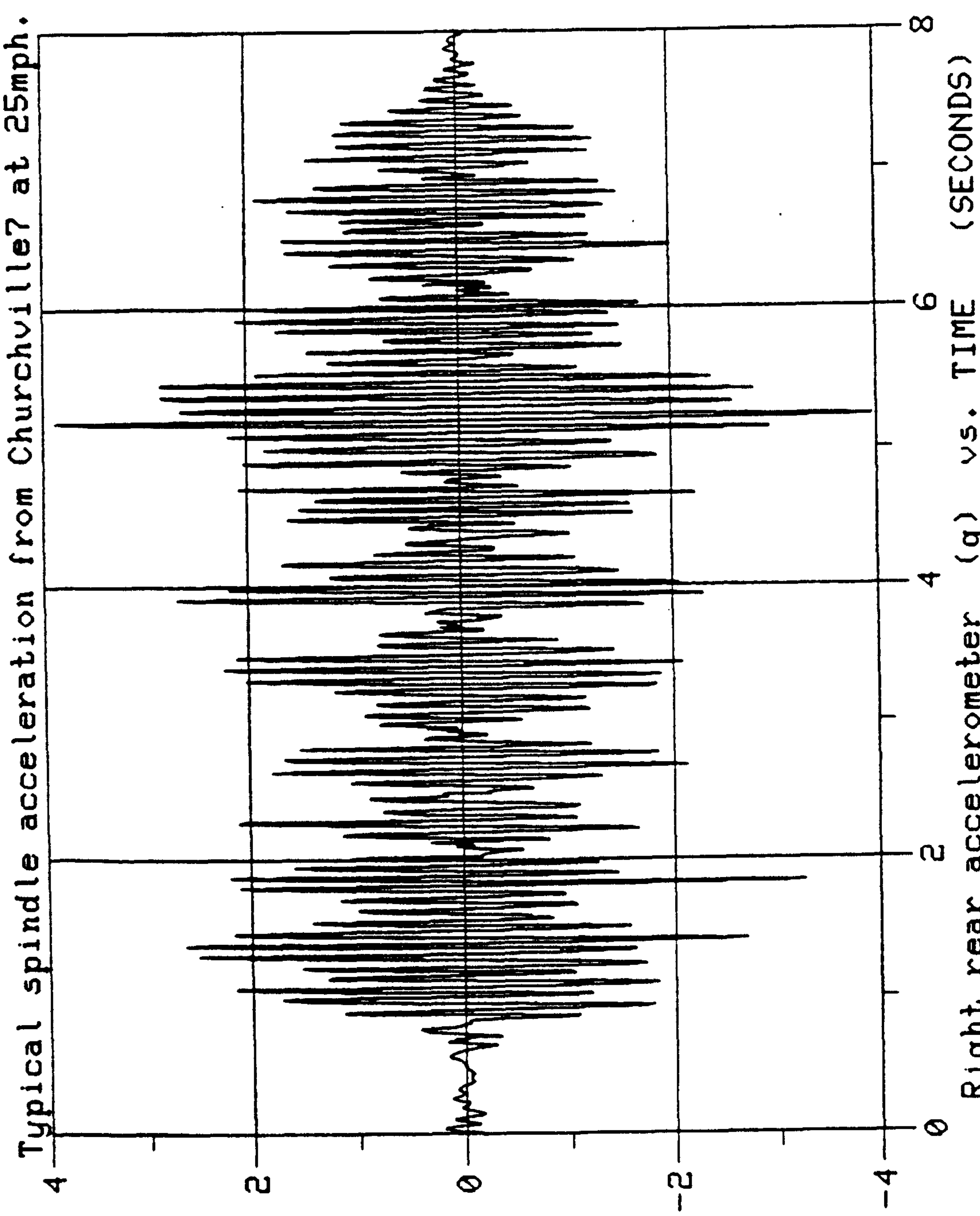

Typical spindle acceleration from Churchville7 at 25mph.
Right rear accelerometer (g) vs. TIME (SECONDS)
0
2
4
6
8
4
2
0
-2
-4

Figure 32

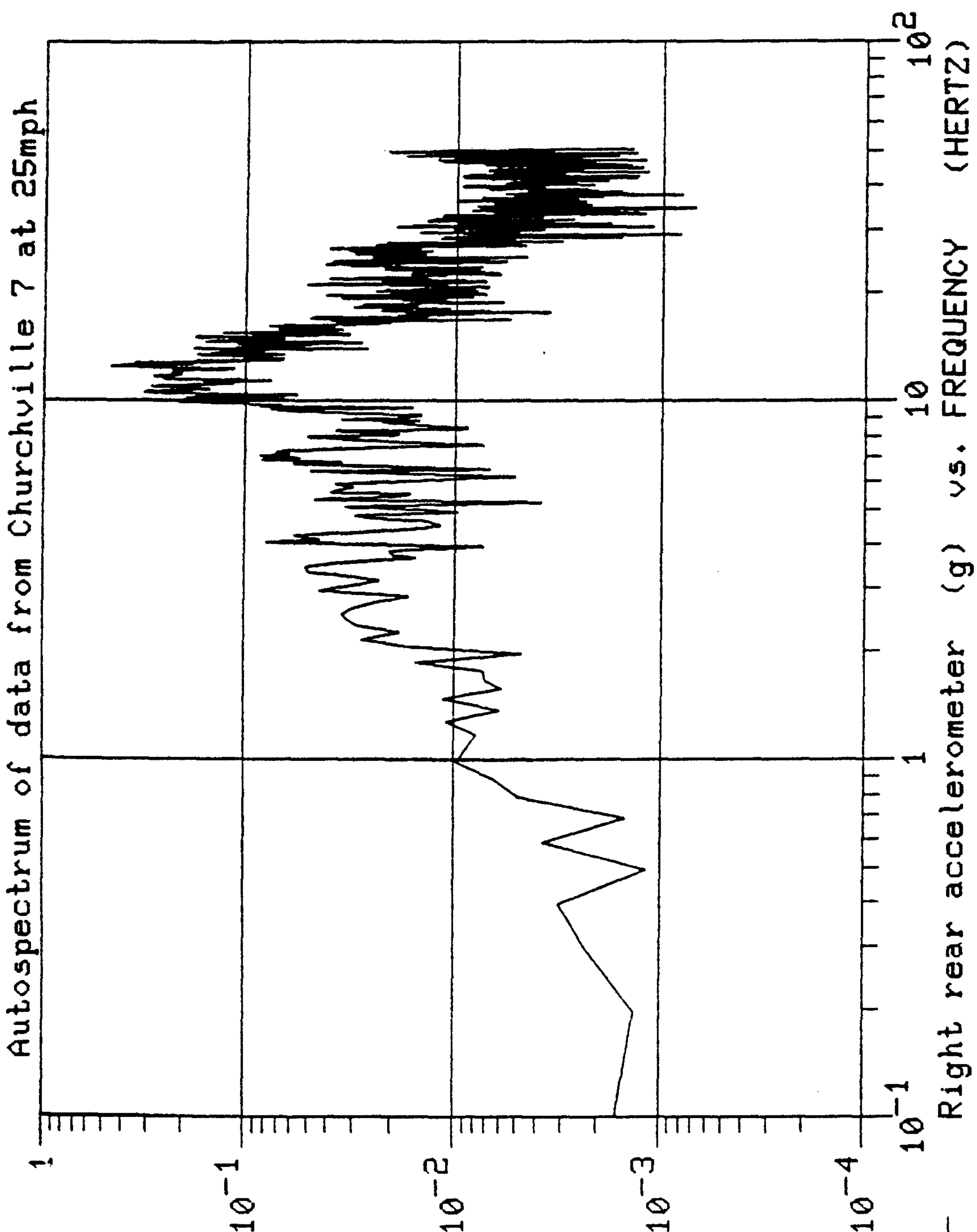

Autospectrum of data from Churchville 7 at 25mph
Right rear accelerometer (g) vs. FREQUENCY (HERTZ)
10^-1
1
10
10^2
1
10^-1
10^-2
10^-3
10^-4

Figure 33

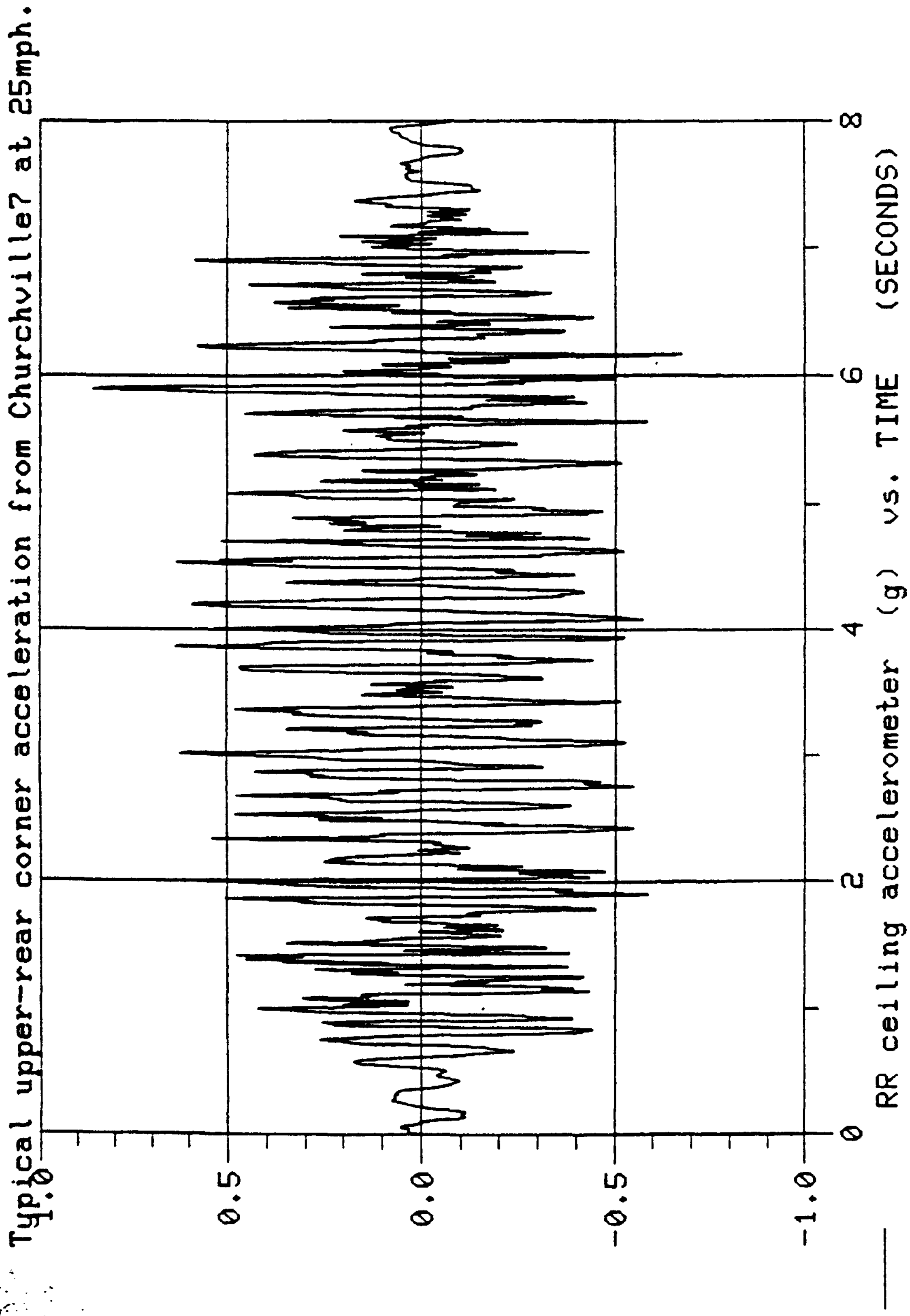

Typical upper-rear corner acceleration from Churchville7 at 25mph.
RR ceiling accelerometer (g) vs. TIME (SECONDS)
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8

Figure 34

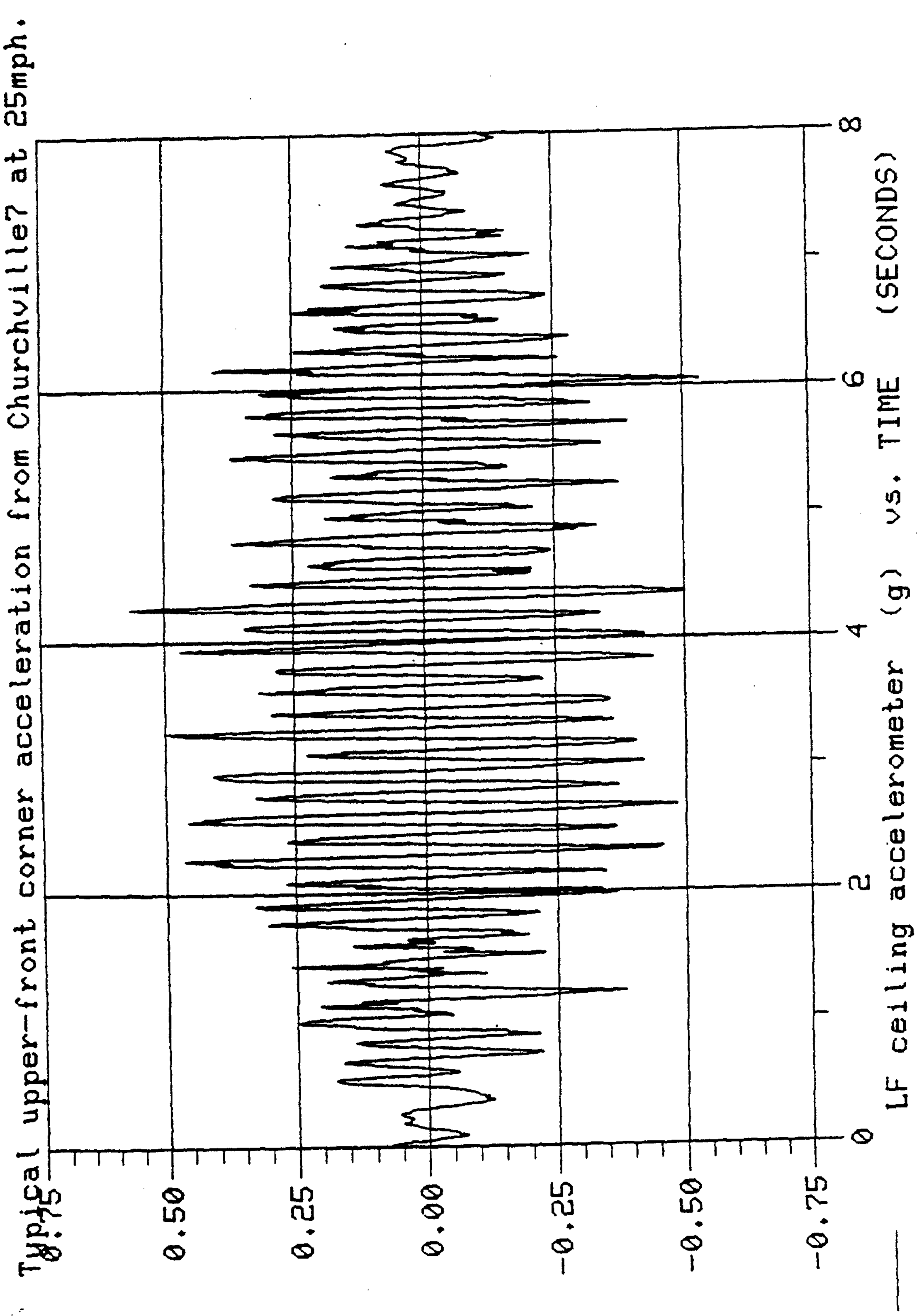

Typical upper-front corner acceleration from Churchville7 at 25mph.
LF ceiling accelerometer (g) vs. TIME (SECONDS)
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
0
2
4
6
8

Figure 35

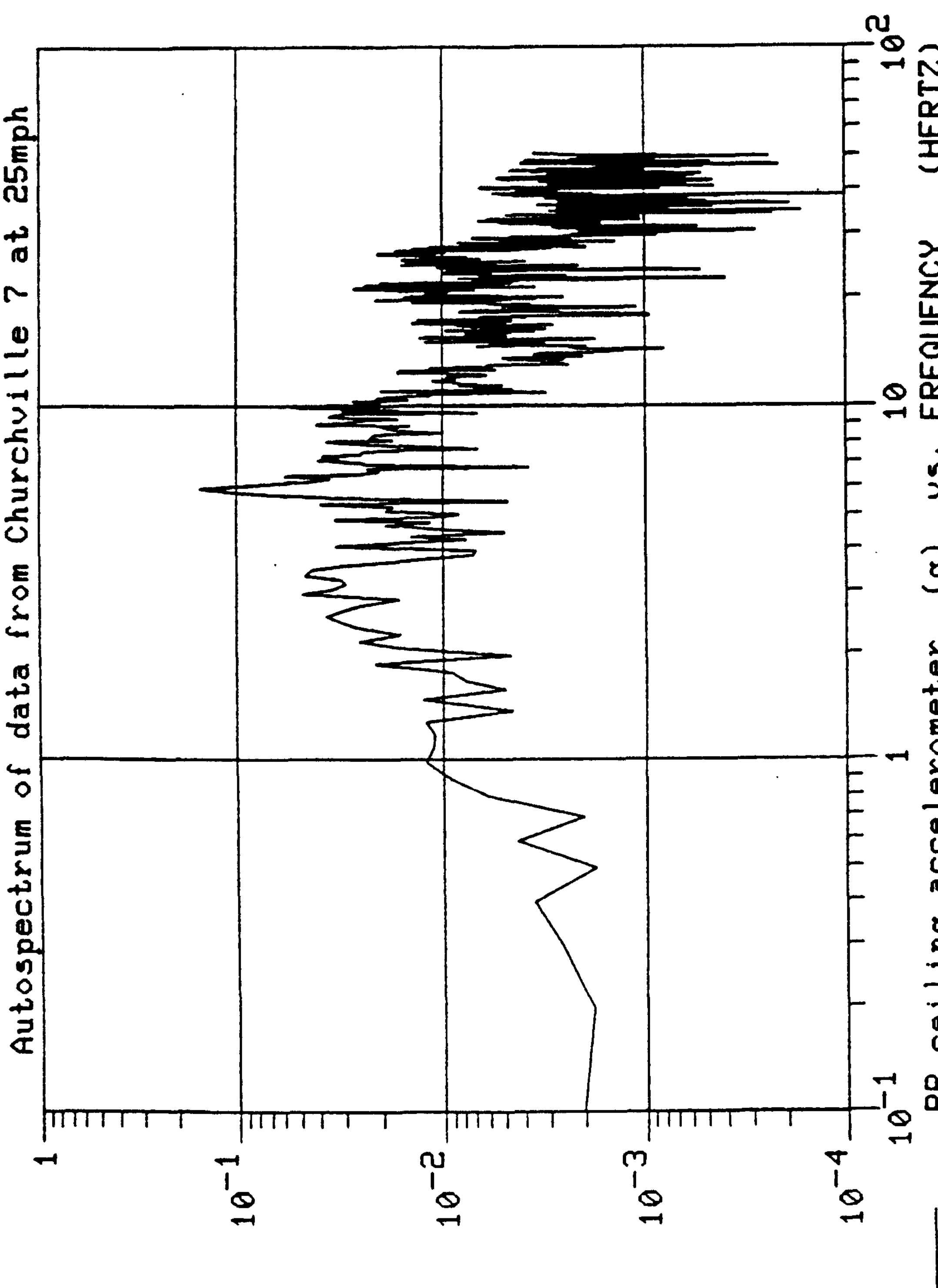
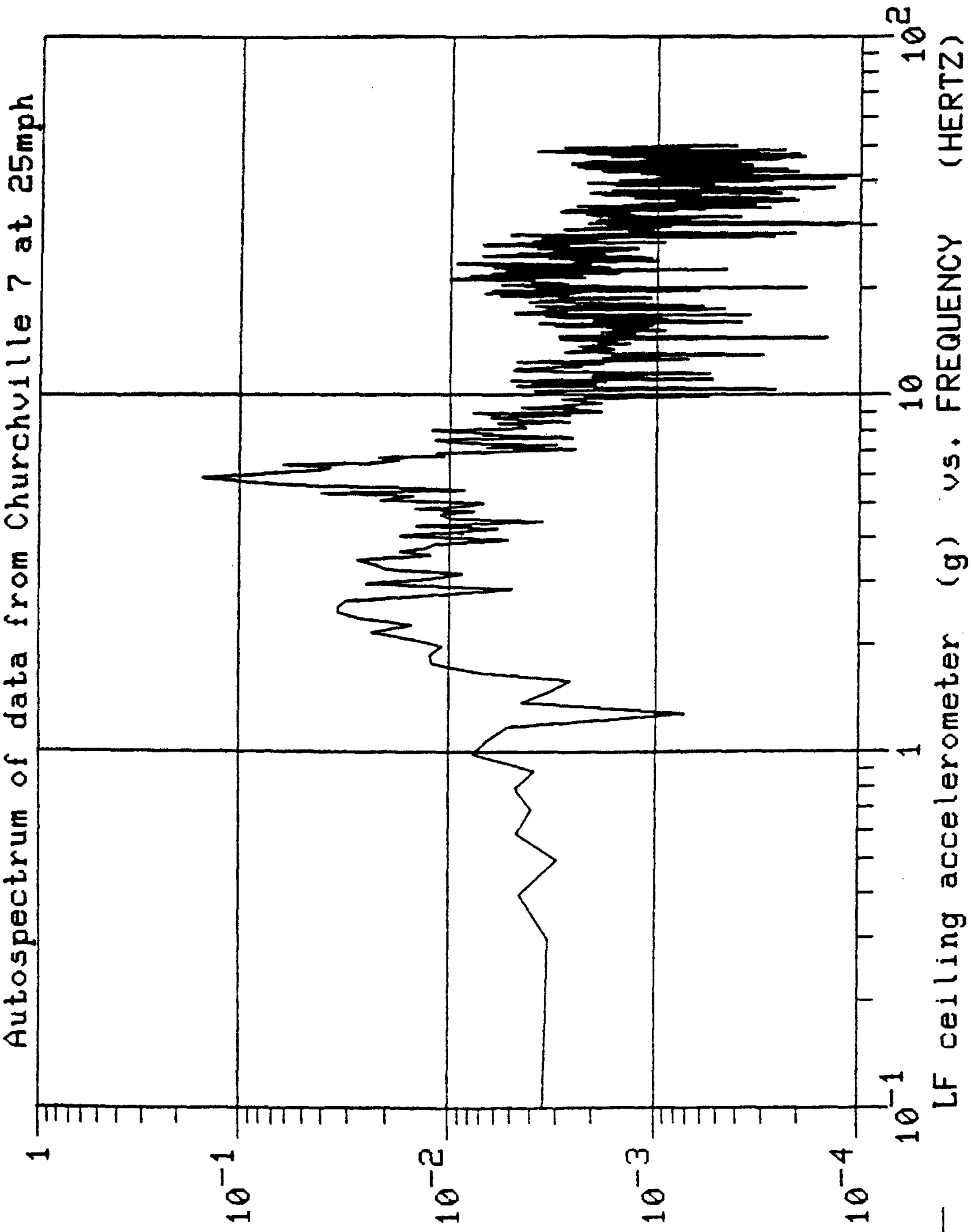
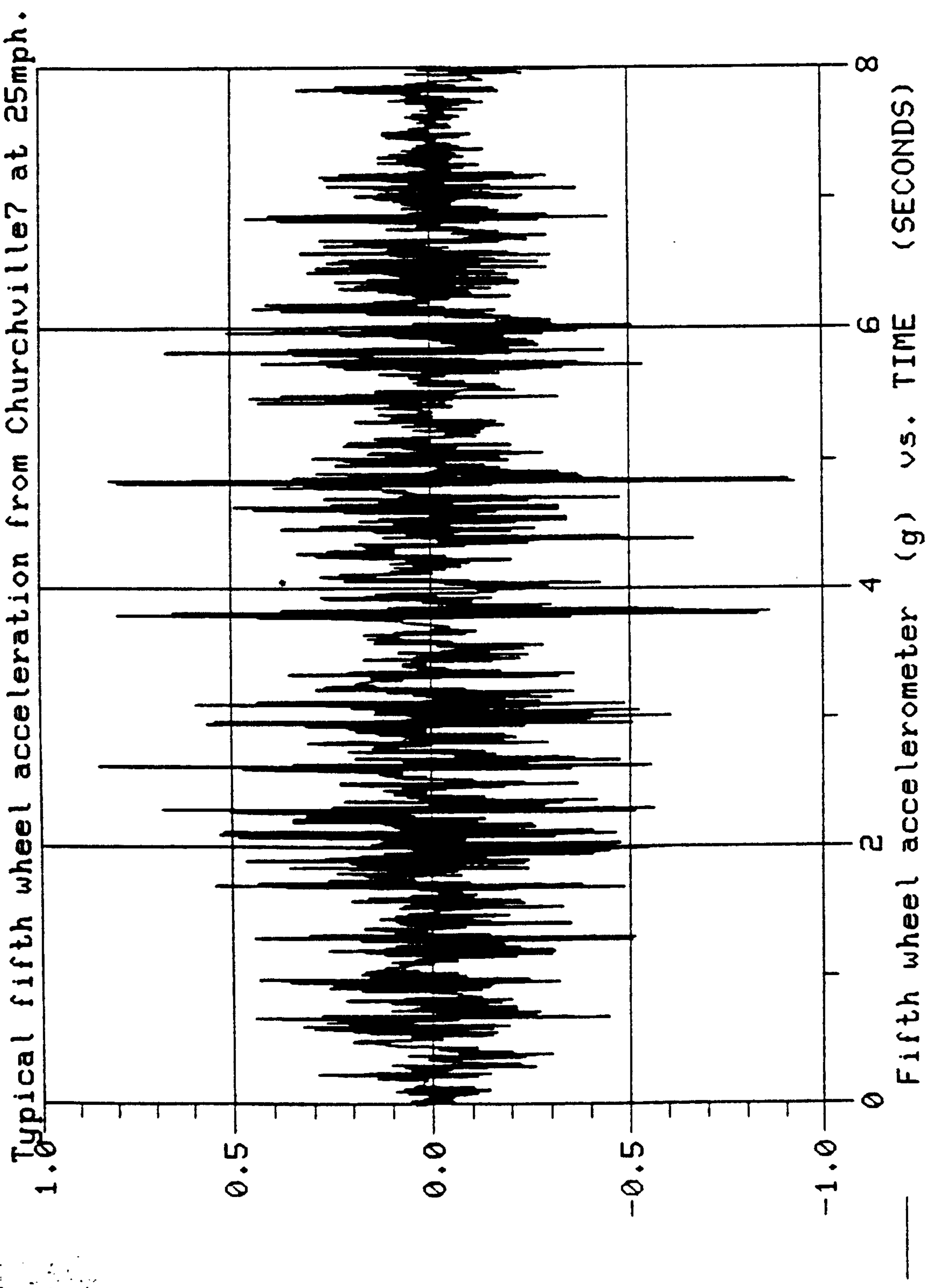

Autospectrum of data from Churchville 7 at 25mph
RR ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 36



Autospectrum of data from Churchville 7 at 25mph
LF ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10
10^2

Figure 37



Typical fifth wheel acceleration from Churchville7 at 25mph.
Fifth wheel accelerometer (g) vs. TIME (SECONDS)
1.0
0.5
0.0
-0.5
-1.0
0
2
4
6
8

Figure 38

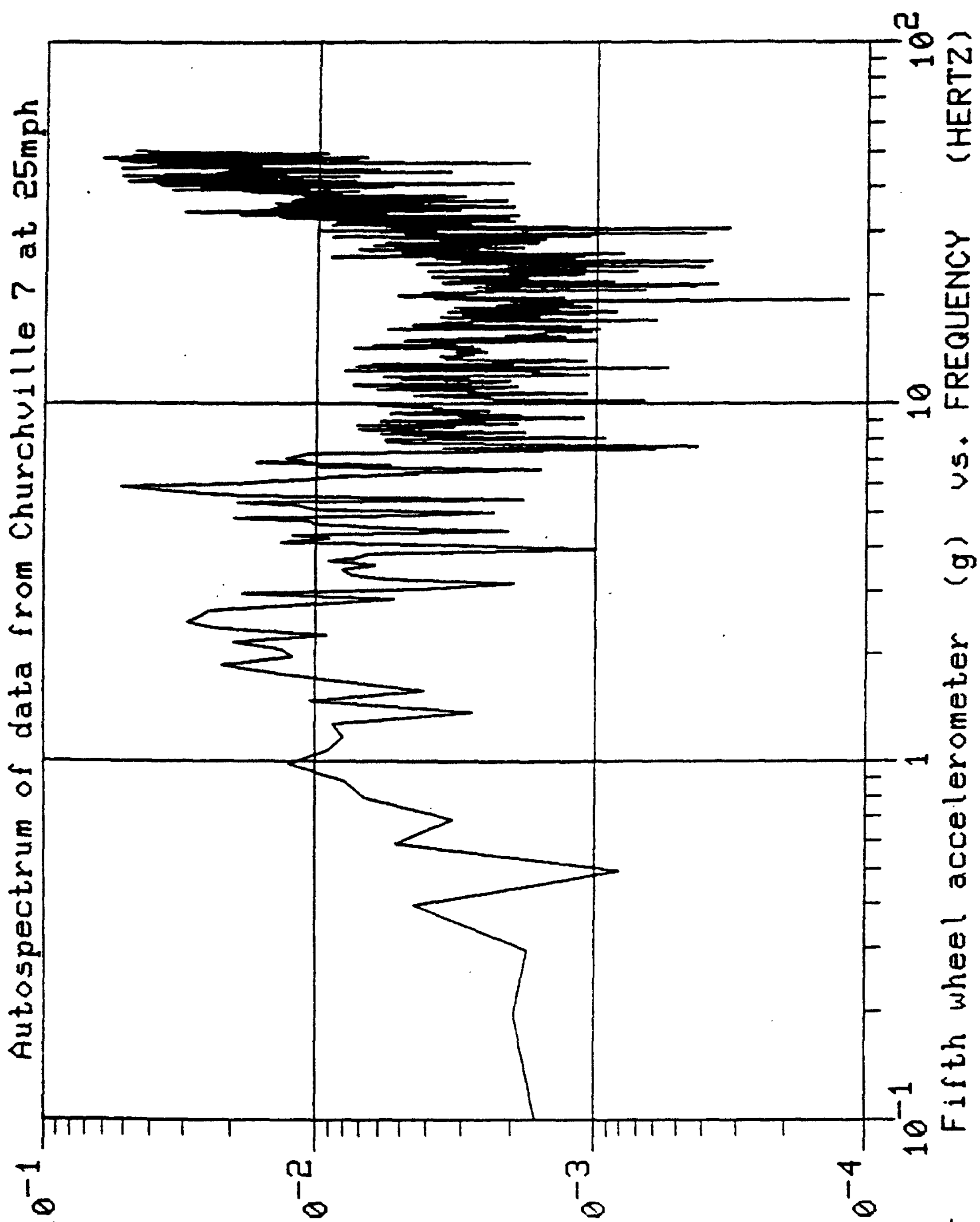

Autospectrum of data from Churchville 7 at 25mph
Fifth wheel accelerometer (g) vs. FREQUENCY (HERTZ)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-1}
1
10
10^{2}

Figure 39

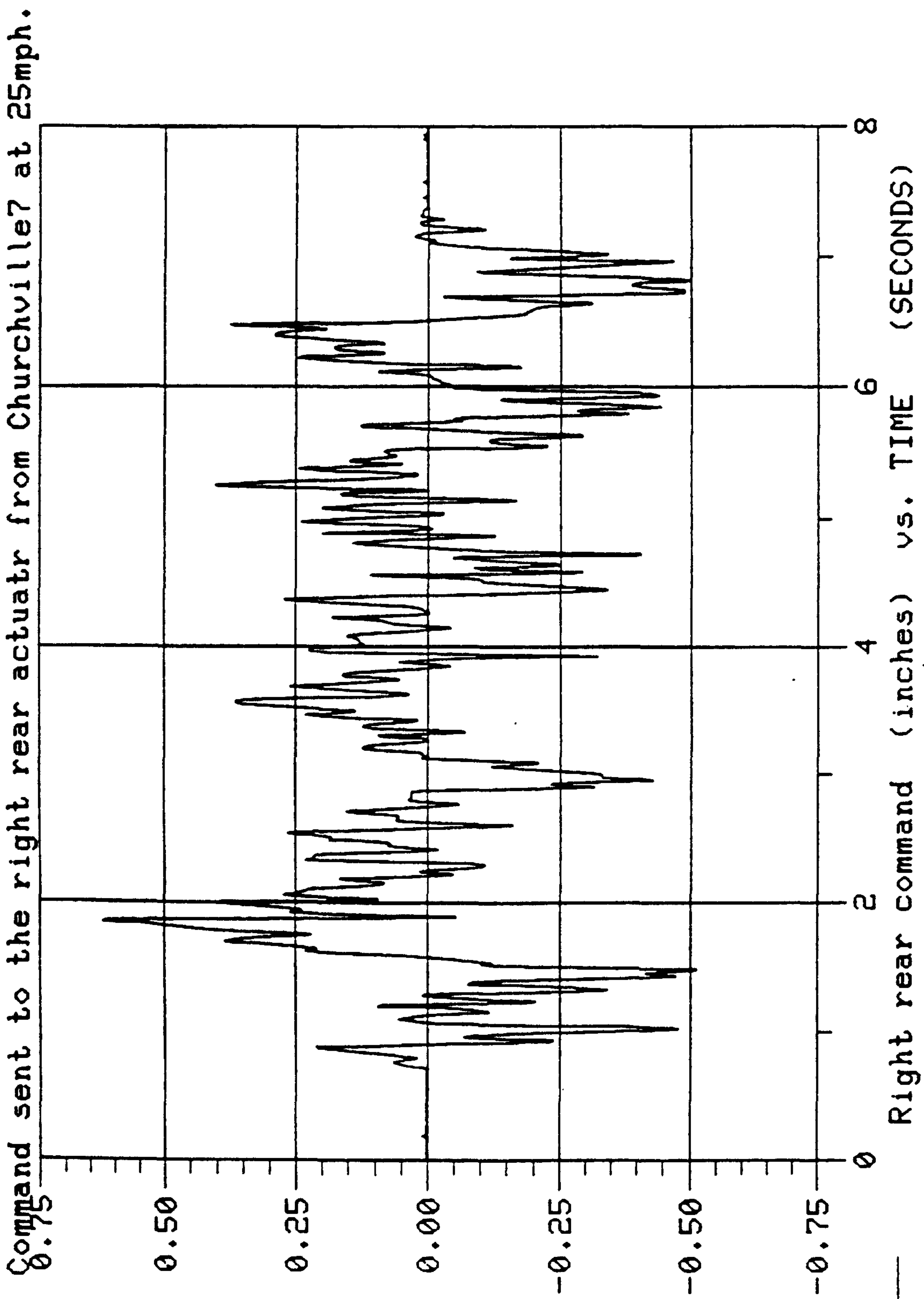

Command sent to the right rear actuatr from Churchville7 at 25mph.
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
0
2
4
6
8
Right rear command (inches) vs. TIME (SECONDS)

Figure 40

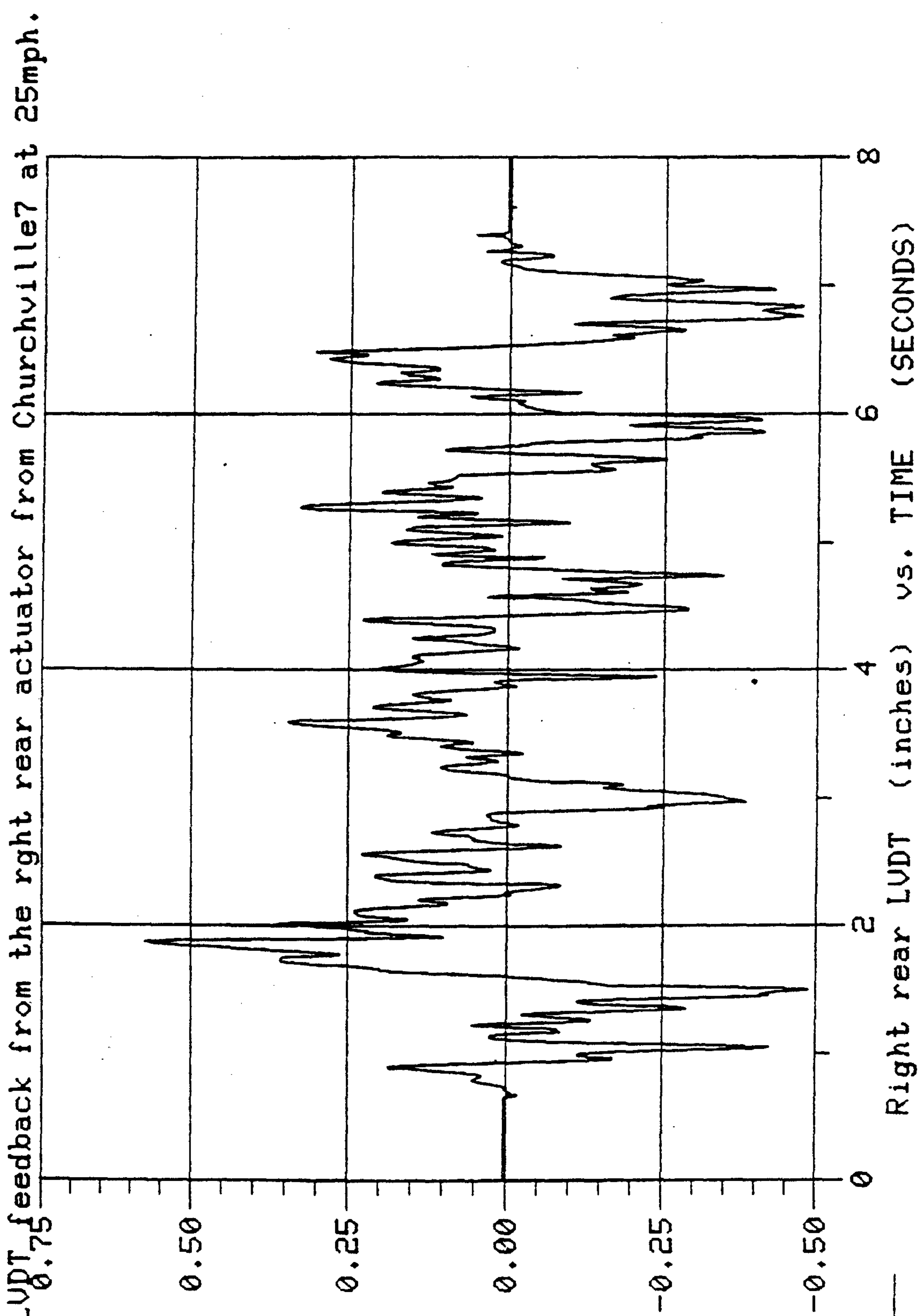

LVDT feedback from the rght rear actuator from Churchville7 at 25mph.
Right rear LVDT (inches) vs. TIME (SECONDS)
0.75
0.50
0.25
0.00
-0.25
-0.50
0
2
4
6
8

Figure 41

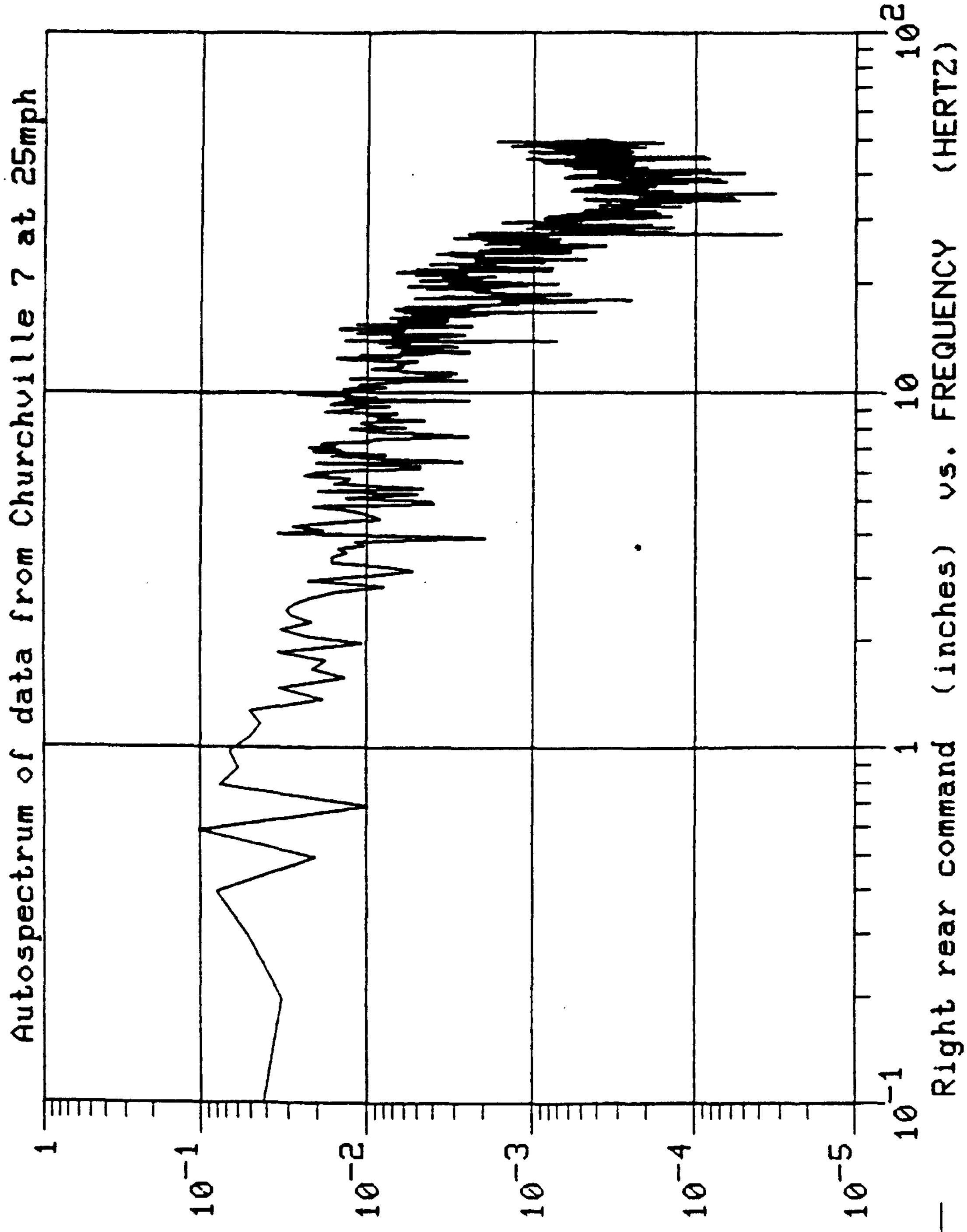

Autospectrum of data from Churchville 7 at 25mph
Right rear command (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 42

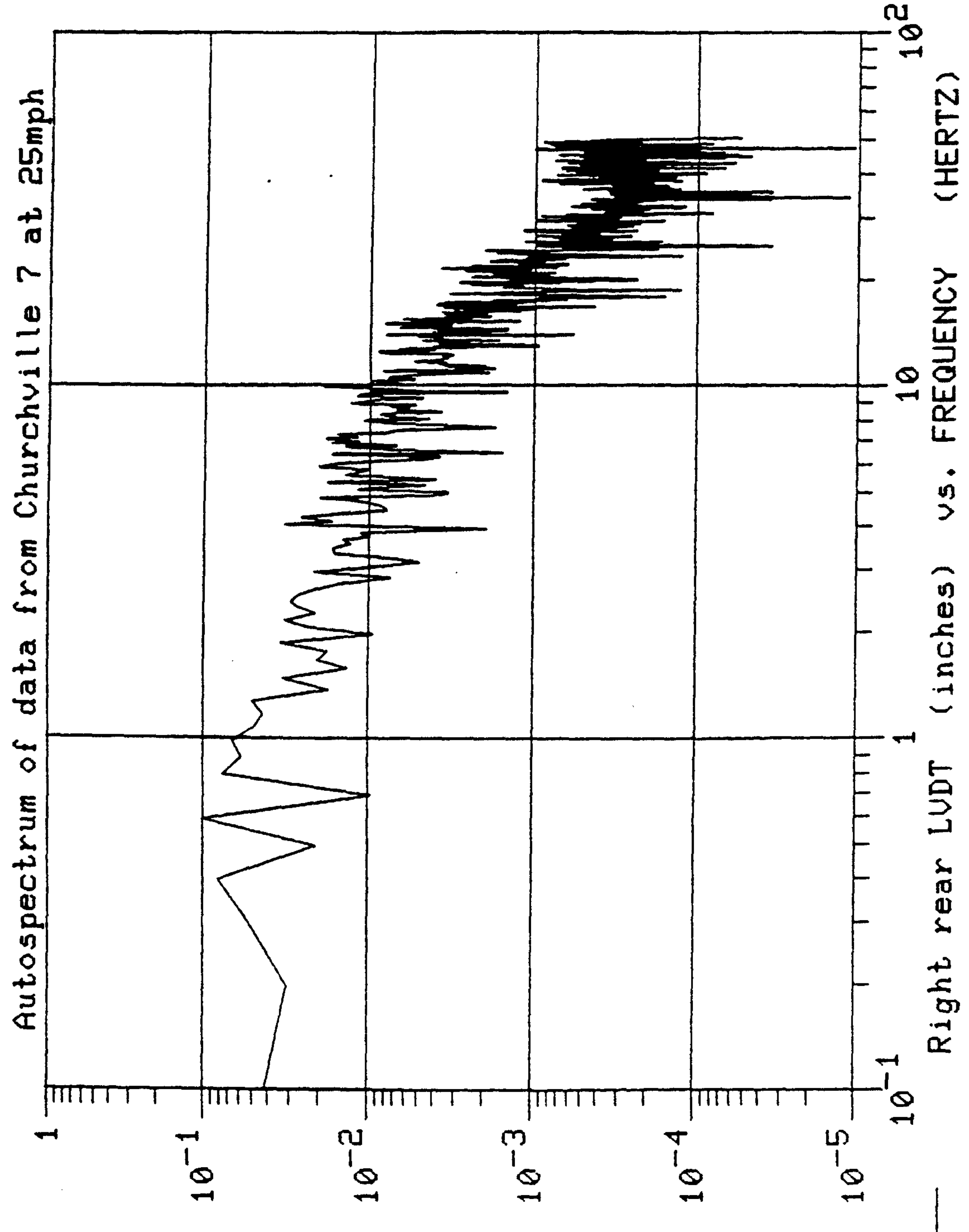

Autospectrum of data from Churchville 7 at 25mph
Right rear LVDT (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 43

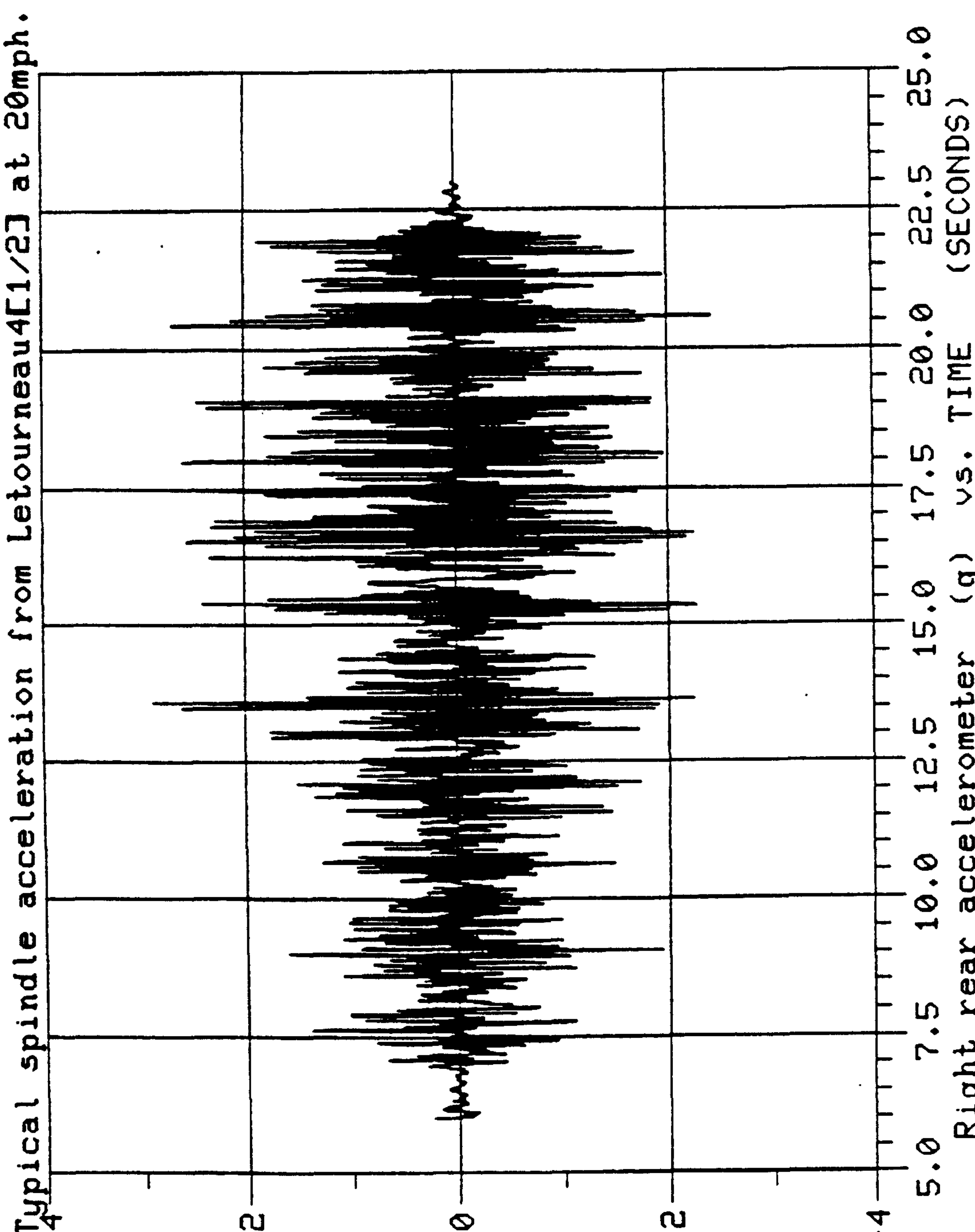

Typical spindle acceleration from Letourneau4[1/2] at 20mph.
Right rear accelerometer (g) vs. TIME (SECONDS)
4
2
0
-2
-4
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0

Figure 44

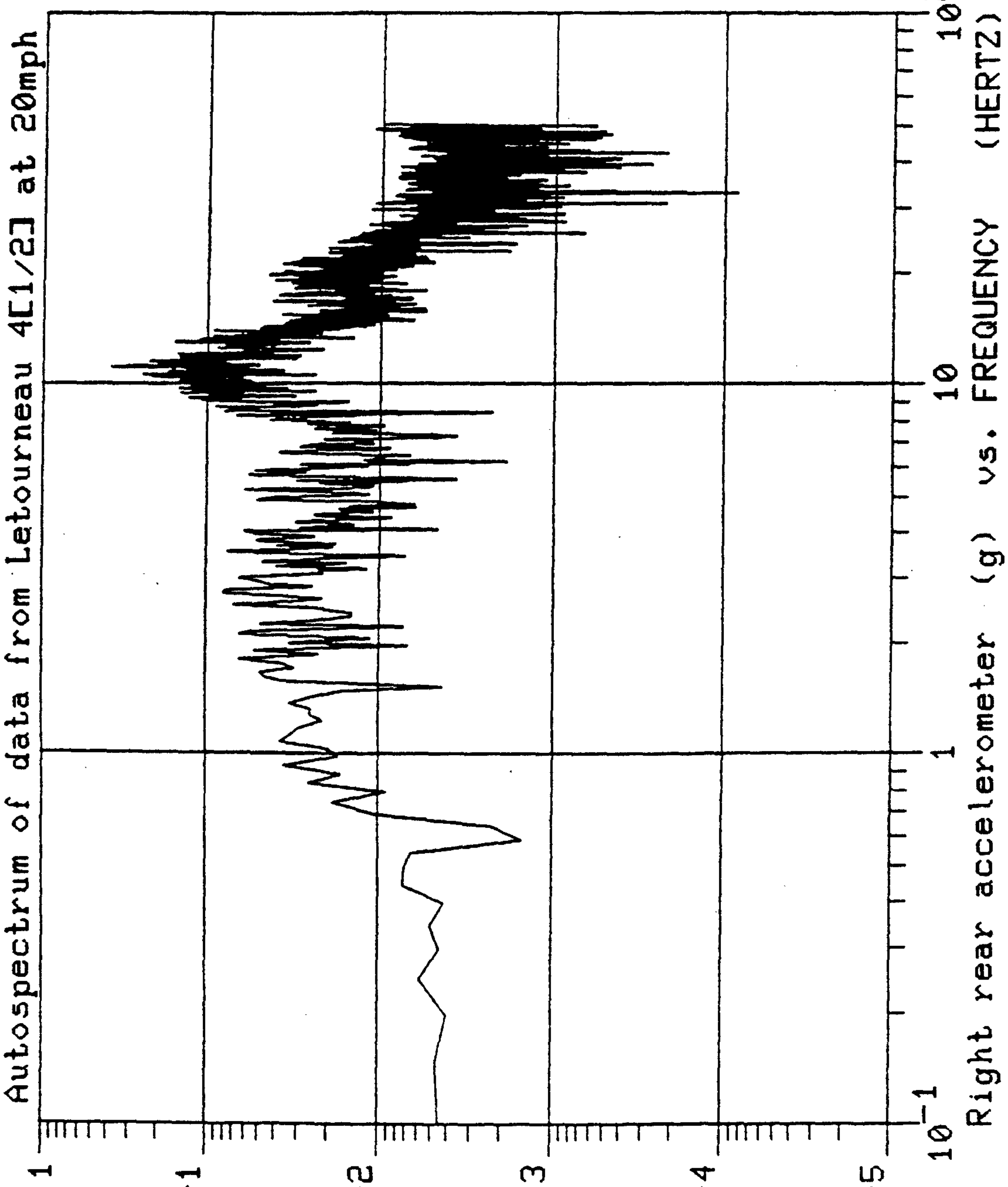

Autospectrum of data from Letourneau 4[1/2] at 20mph
Right rear accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 45

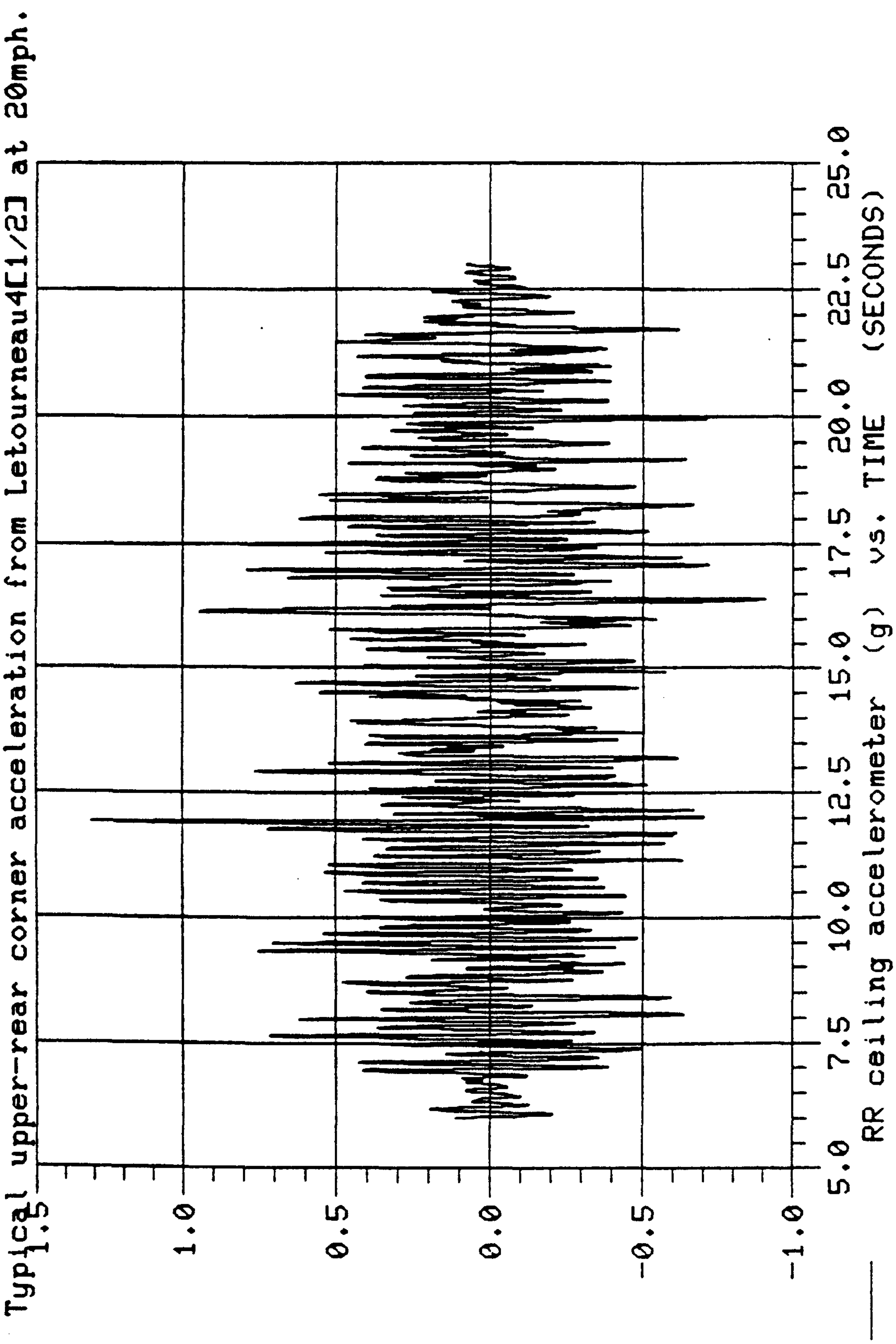

Typical upper-rear corner acceleration from Letourneau4[1/2] at 20mph.
1.5
1.0
0.5
0.0
-0.5
-1.0
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
RR ceiling accelerometer (g) vs. TIME (SECONDS)

Figure 46

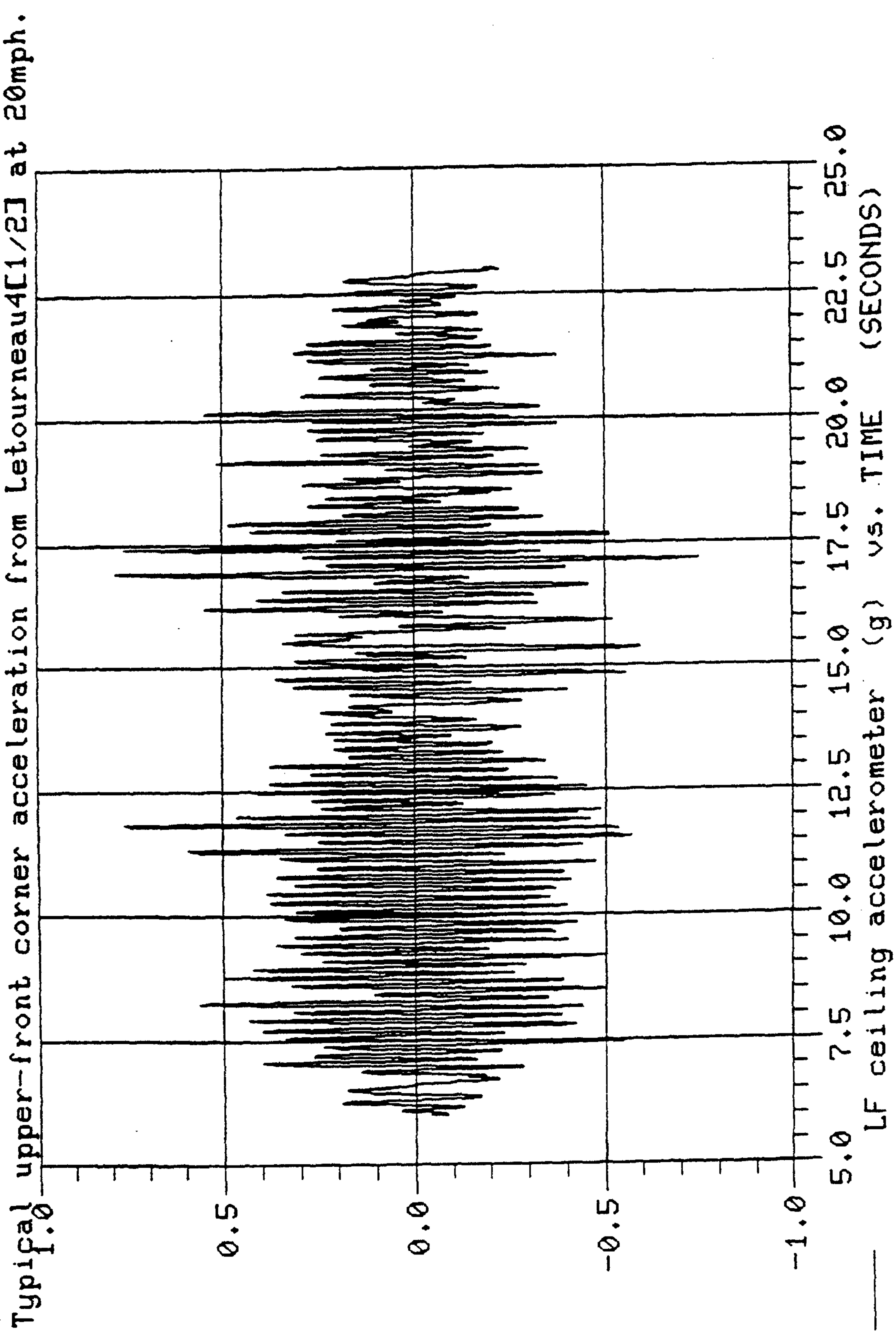

Typical upper-front corner acceleration from Letourneau4[1/2] at 20mph.
1.0
0.5
0.0
-0.5
-1.0
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
LF ceiling accelerometer (g) vs. TIME (SECONDS)

Figure 47

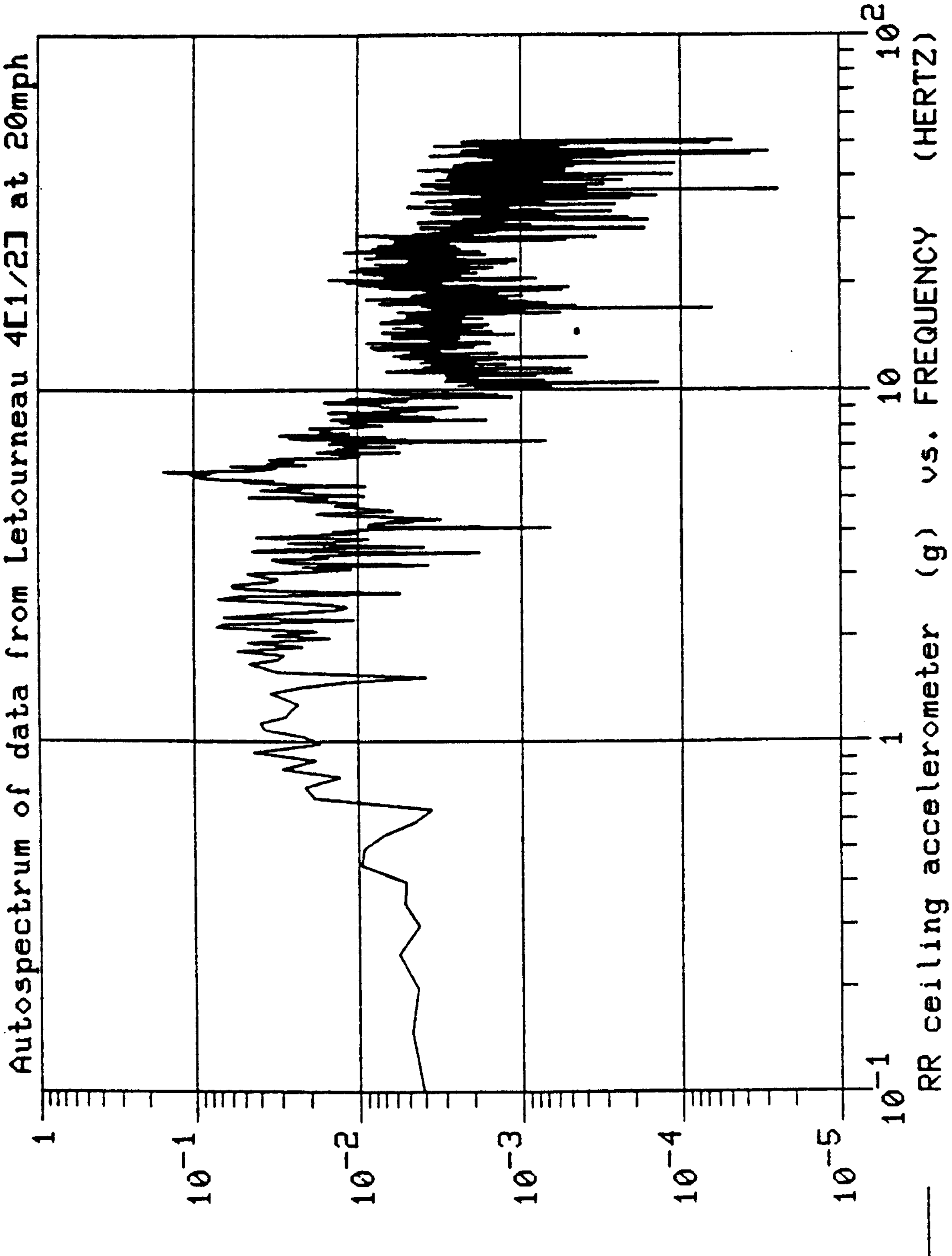
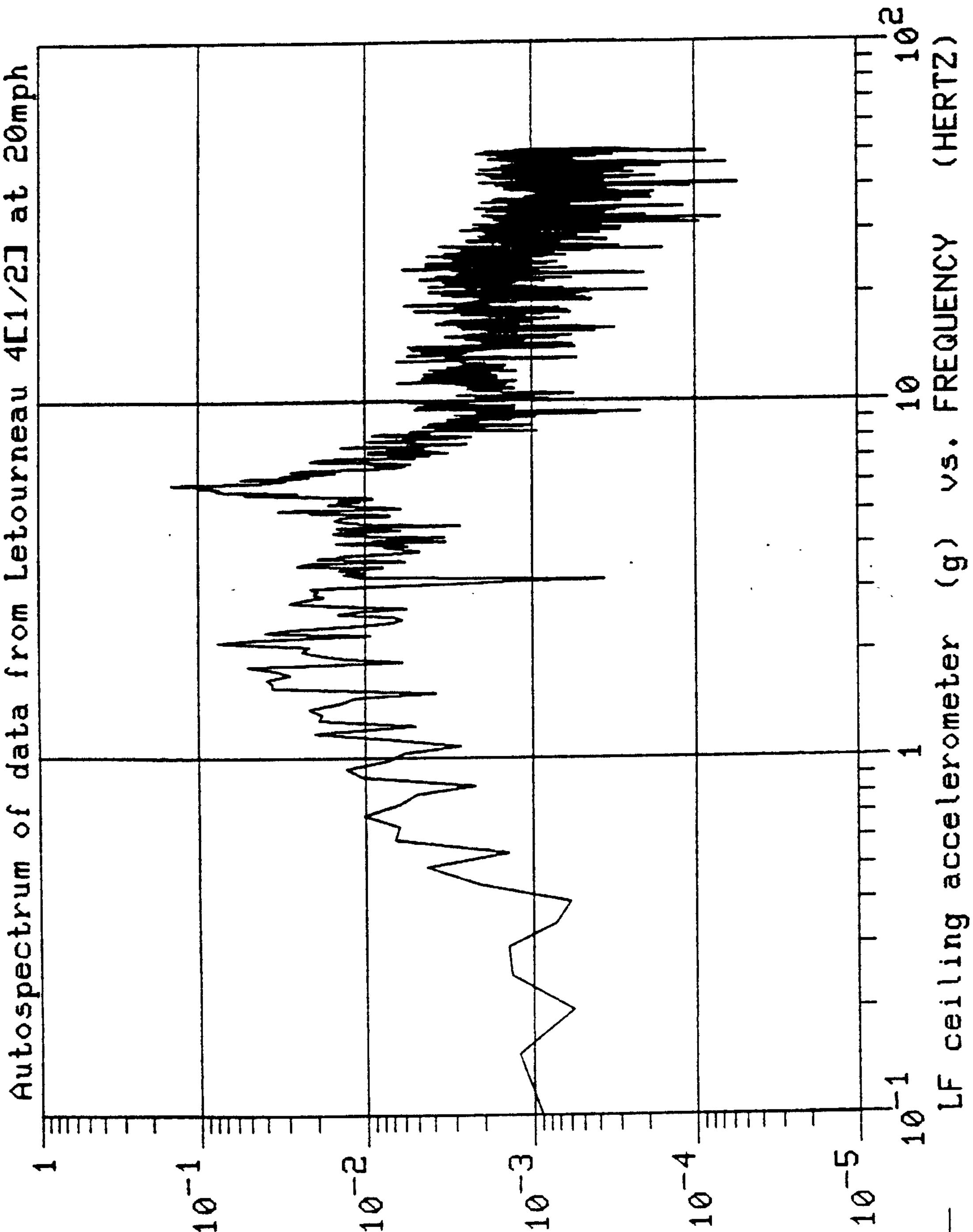

Autospectrum of data from Letourneau 4[1/2] at 20mph
RR ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 48



Autospectrum of data from Letourneau 4[1/2] at 20mph
LF ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10
10^2

Figure 49

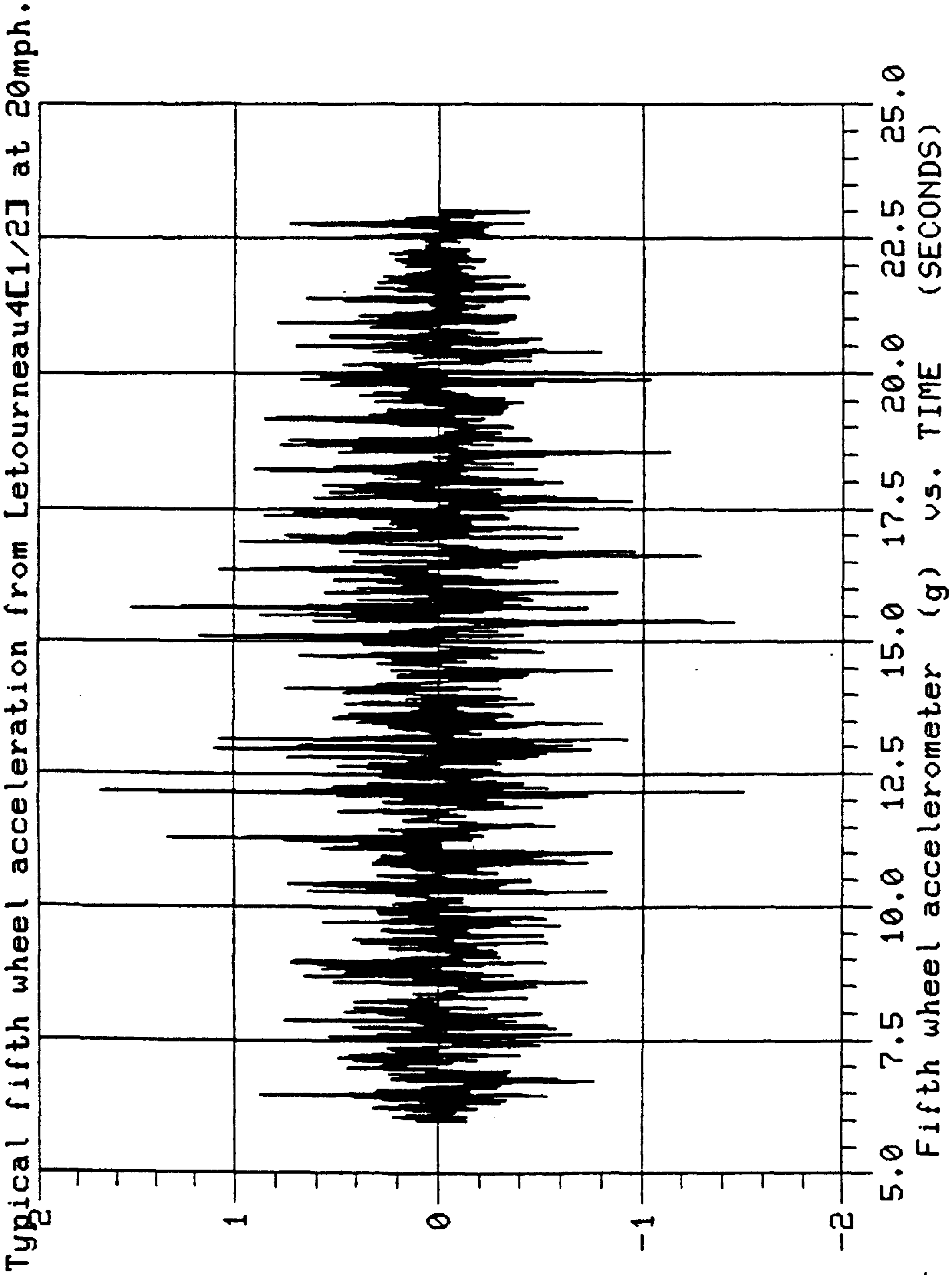
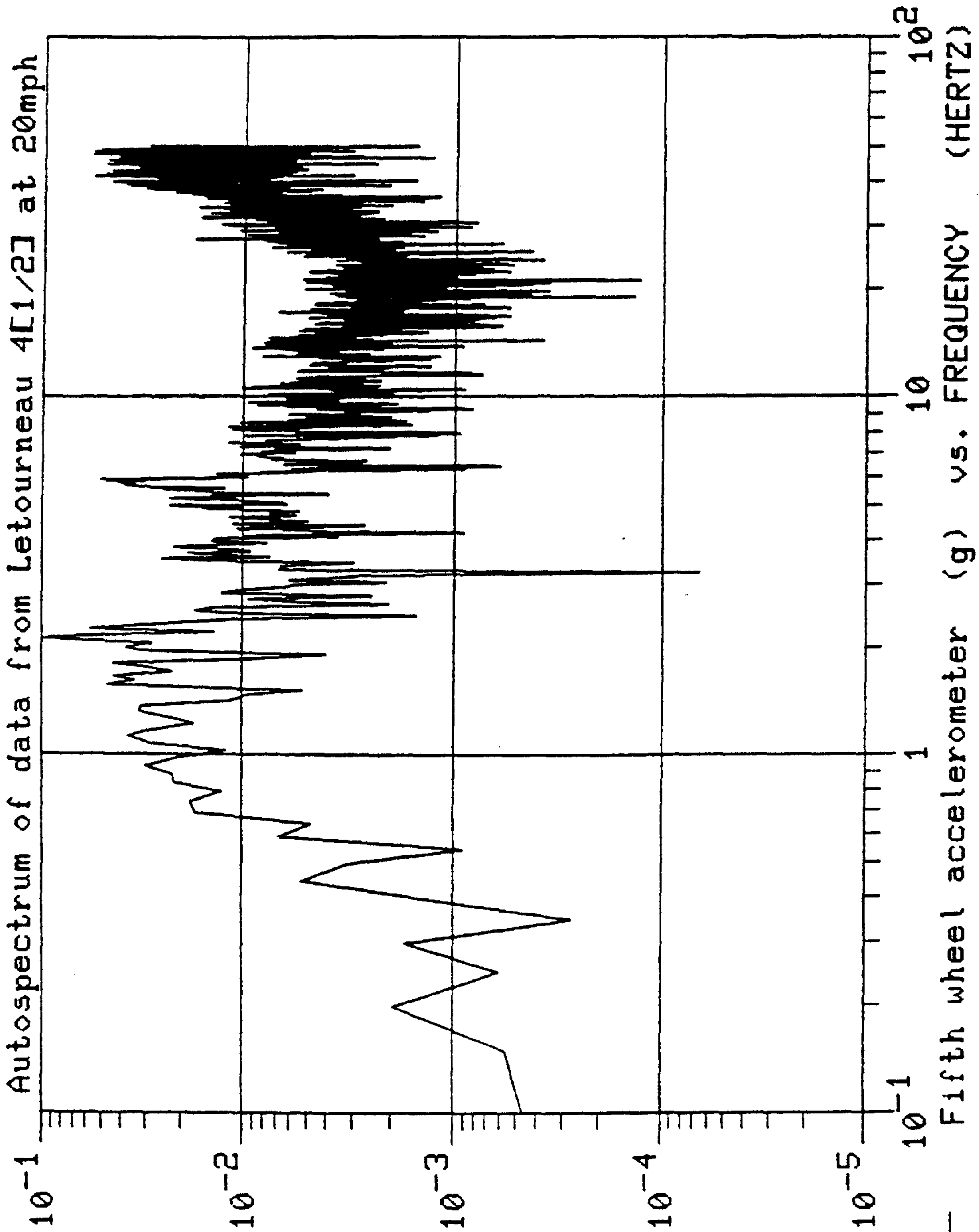

Typical fifth wheel acceleration from Letourneau4[1/2] at 20mph.
2
1
0
-1
-2
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
Fifth wheel accelerometer (g) vs. TIME (SECONDS)

Figure 50



Autospectrum of data from Letourneau 4[1/2] at 20mph
Fifth wheel accelerometer (g) vs. FREQUENCY (HERTZ)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 51

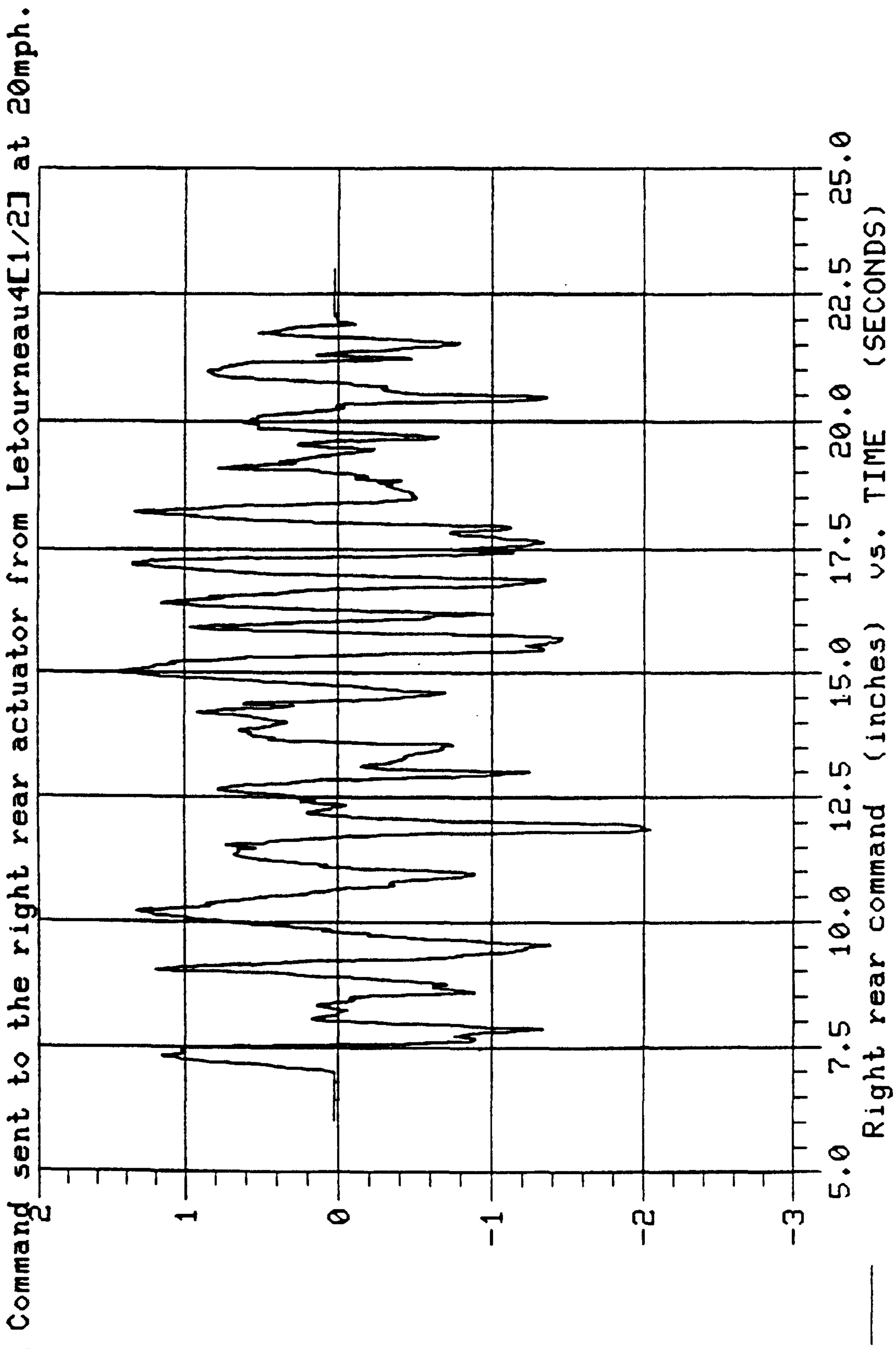

Command sent to the right rear actuator from Letourneau4[1/2] at 20mph.
Right rear command (inches) vs. TIME (SECONDS)
2
1
0
-1
-2
-3
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0

Figure 52

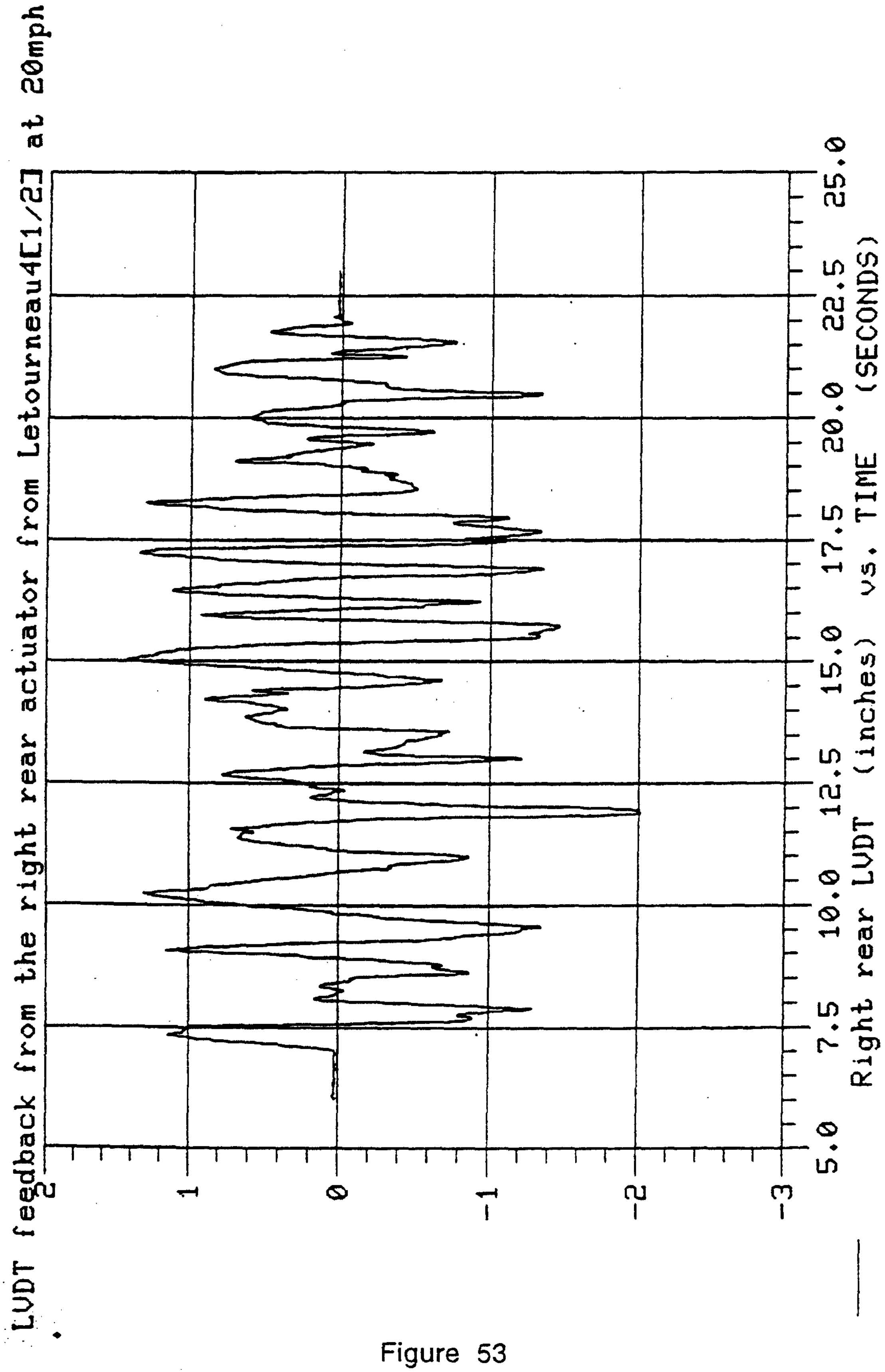

LVDT feedback from the right rear actuator from Letourneau4[1/2] at 20mph
2
1
0
-1
-2
-3
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
Right rear LVDT (inches) vs. TIME (SECONDS)

Figure 53

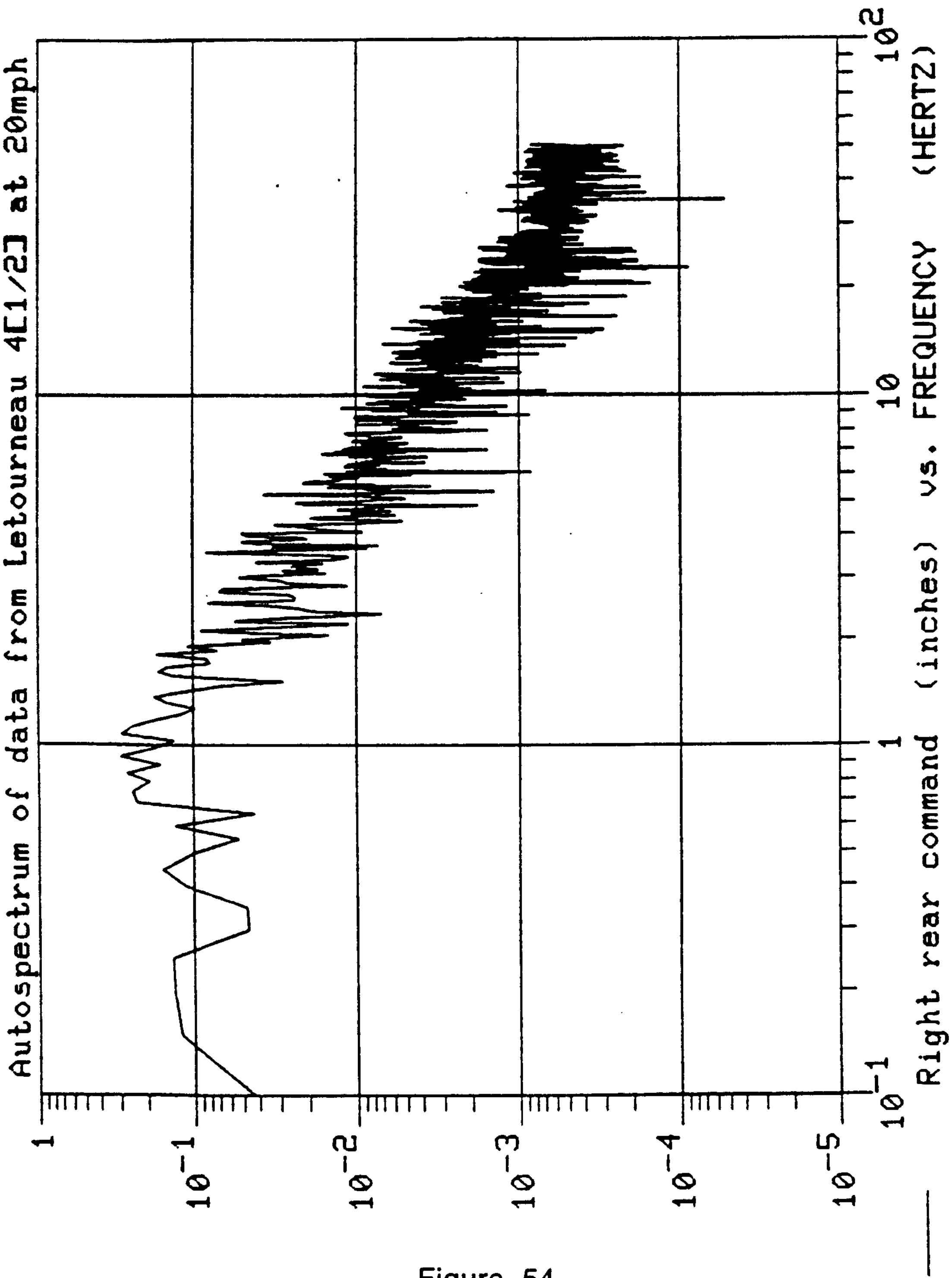

Autospectrum of data from Letourneau 4[1/2] at 20mph
Right rear command (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 54

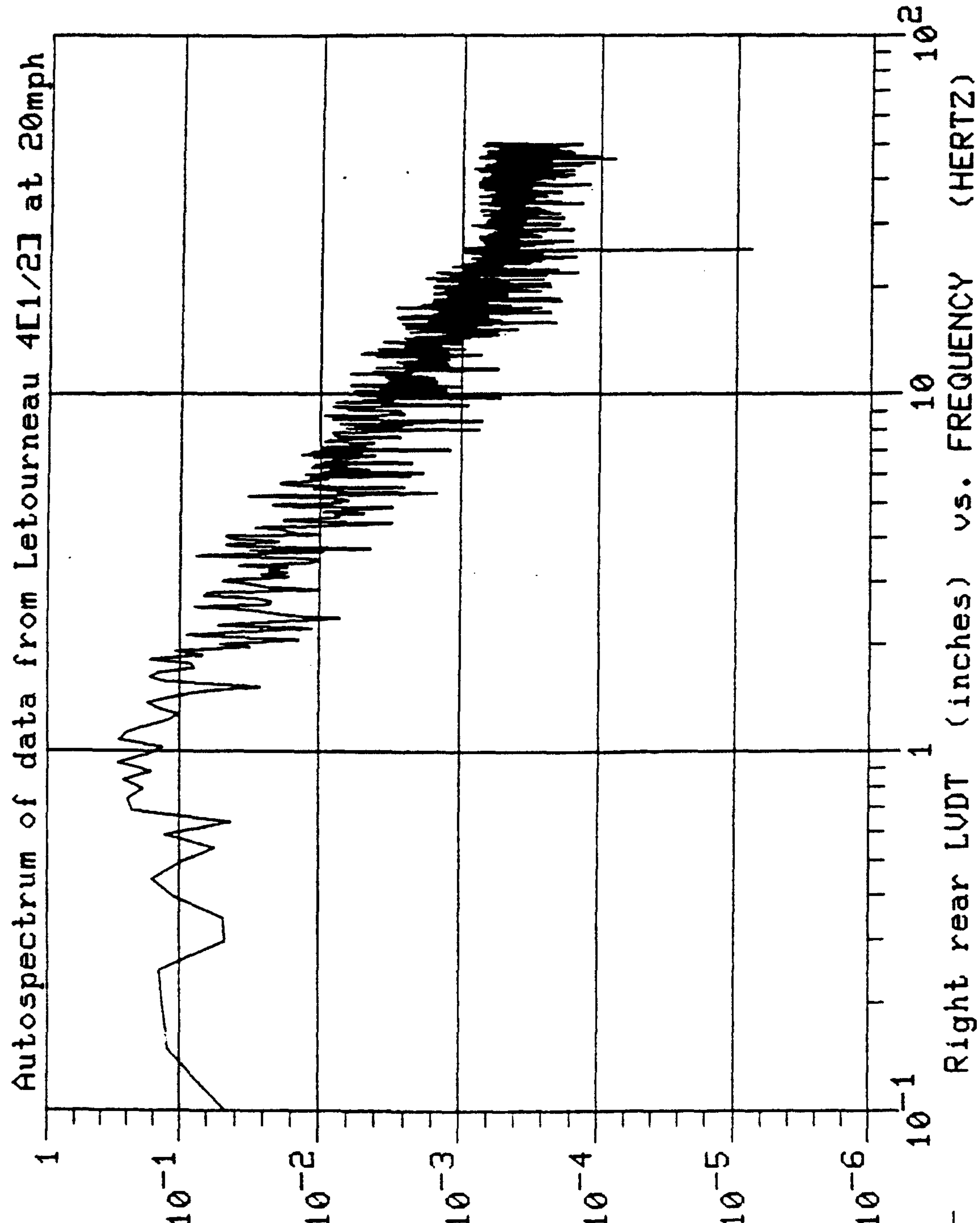

Autospectrum of data from Letourneau 4[1/2] at 20mph
Right rear LVDT (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-1}
1
10
10^{2}

Figure 55

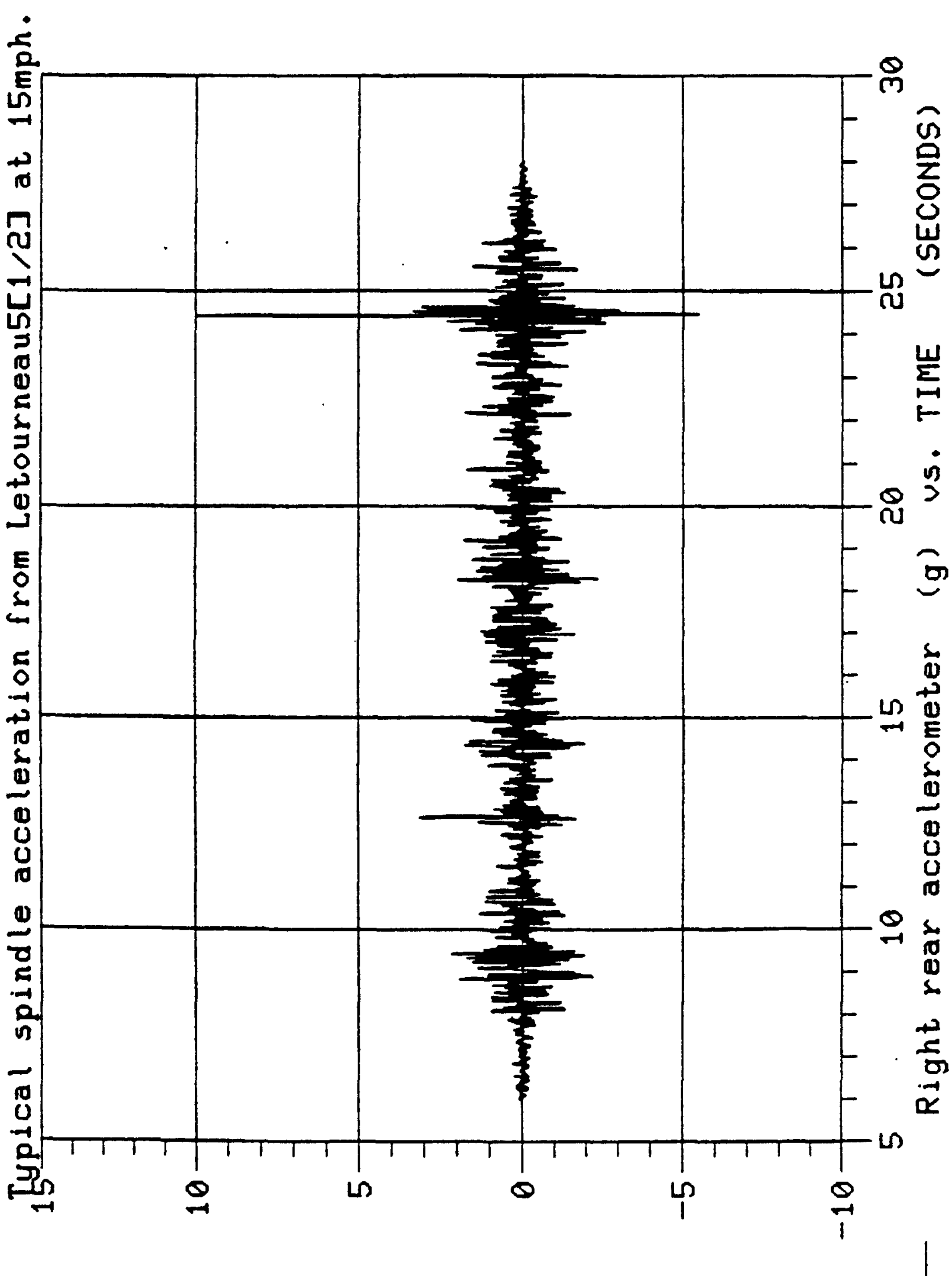

Typical spindle acceleration from Letourneau5[1/2] at 15mph.
15
10
5
0
-5
-10
5
10
15
20
25
30
Right rear accelerometer (g) vs. TIME (SECONDS)

Figure 56

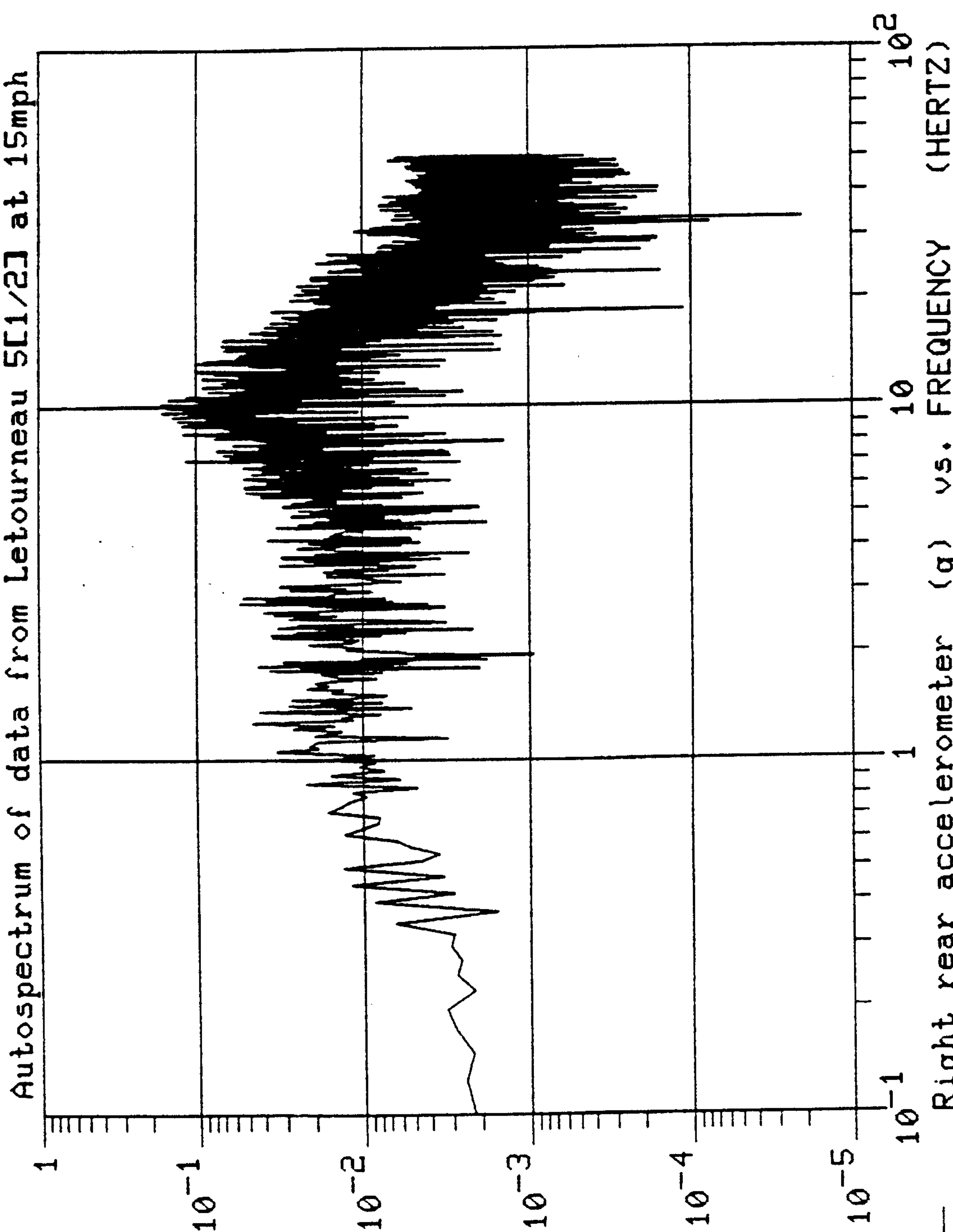

Autospectrum of data from Letourneau 5[1/2] at 15mph
Right rear accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 57

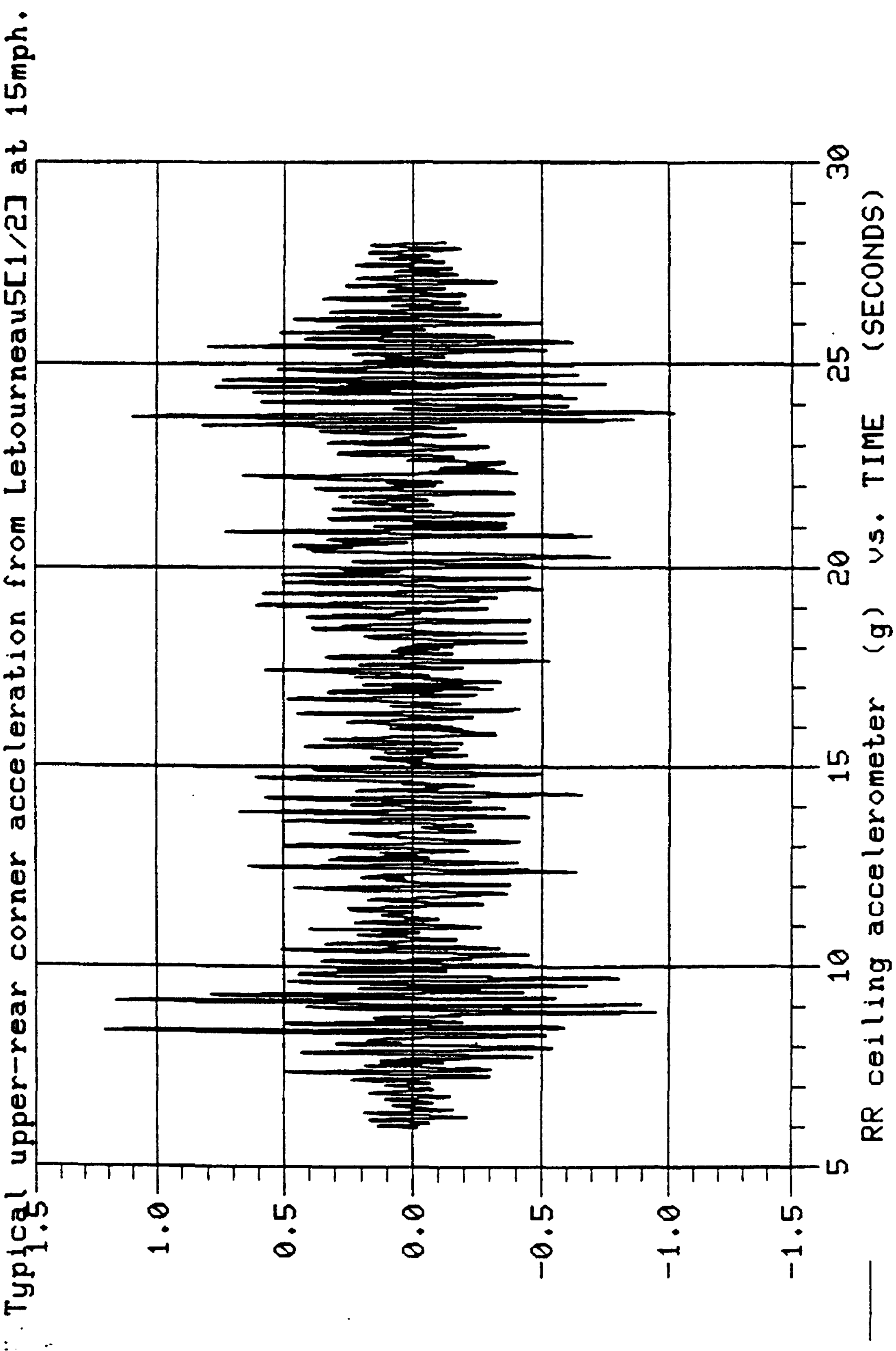
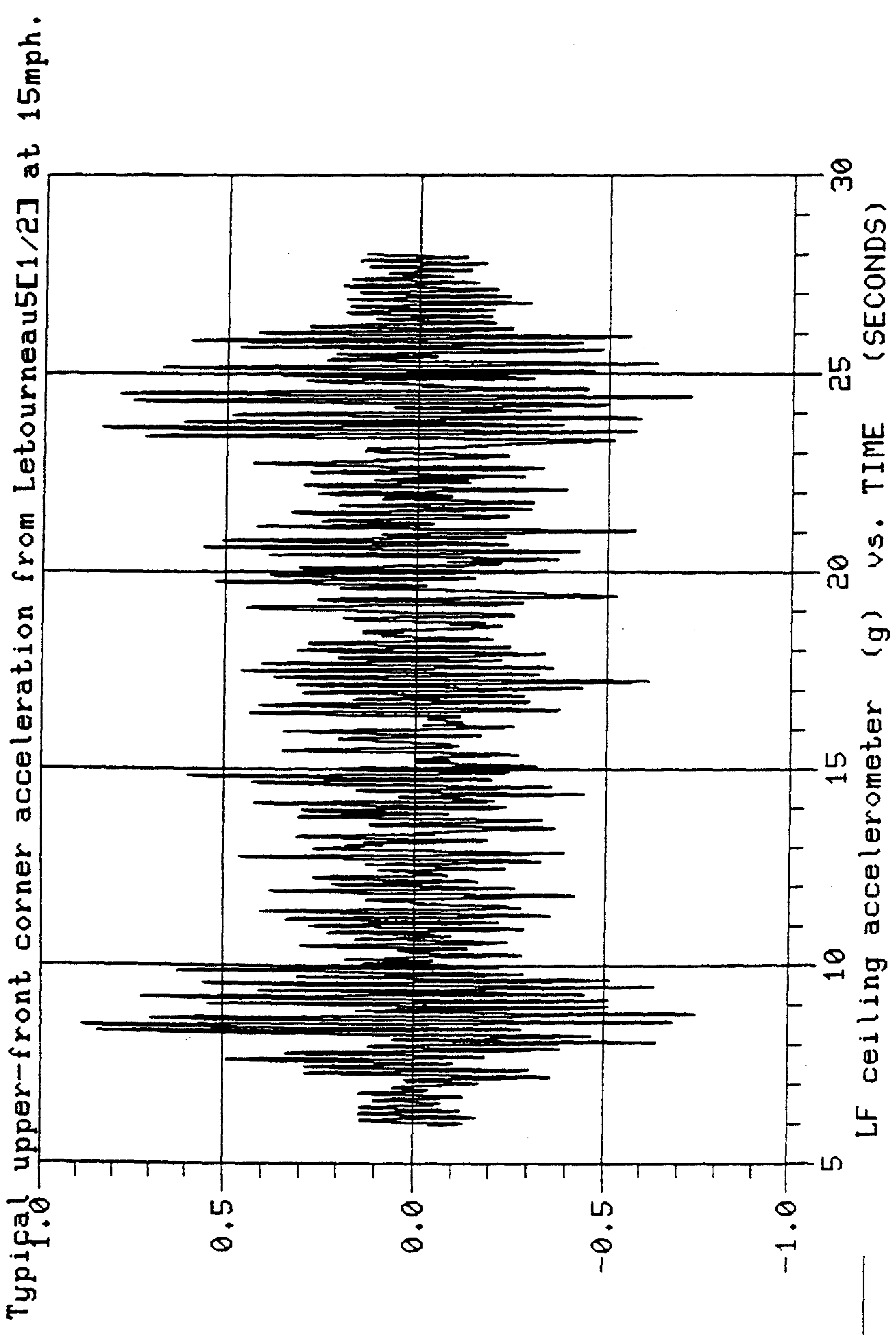

Typical upper-rear corner acceleration from Letourneau5[1/2] at 15mph.
RR ceiling accelerometer (g) vs. TIME (SECONDS)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
5
10
15
20
25
30

Figure 58



Typical upper-front corner acceleration from Letourneau5[1/2] at 15mph.
LF ceiling accelerometer (g) vs. TIME (SECONDS)
1.0
0.5
0.0
-0.5
-1.0
5
10
15
20
25
30

Figure 59

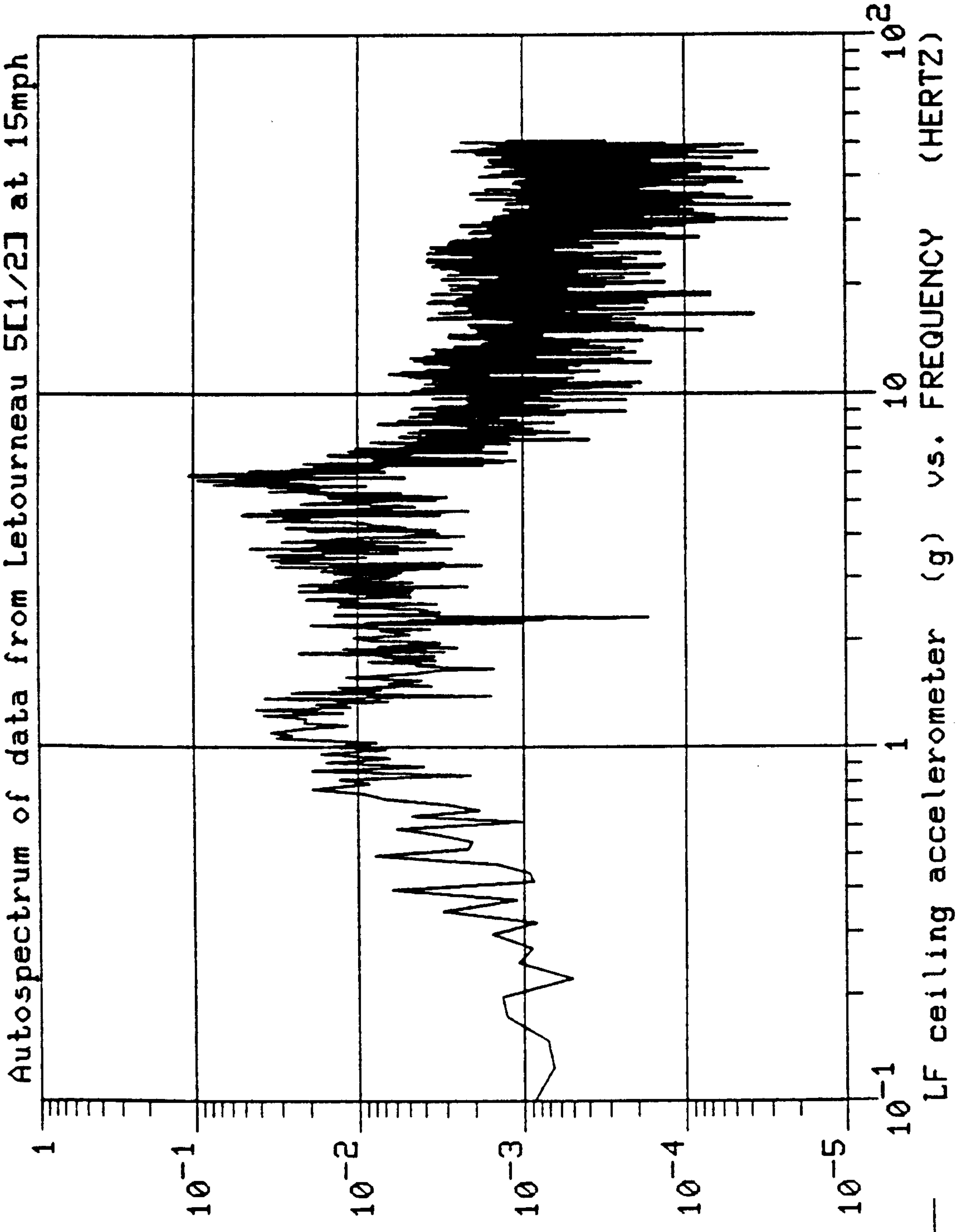

Autospectrum of data from Letourneau 5[1/2] at 15mph
LF ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10
10^2

Figure 60

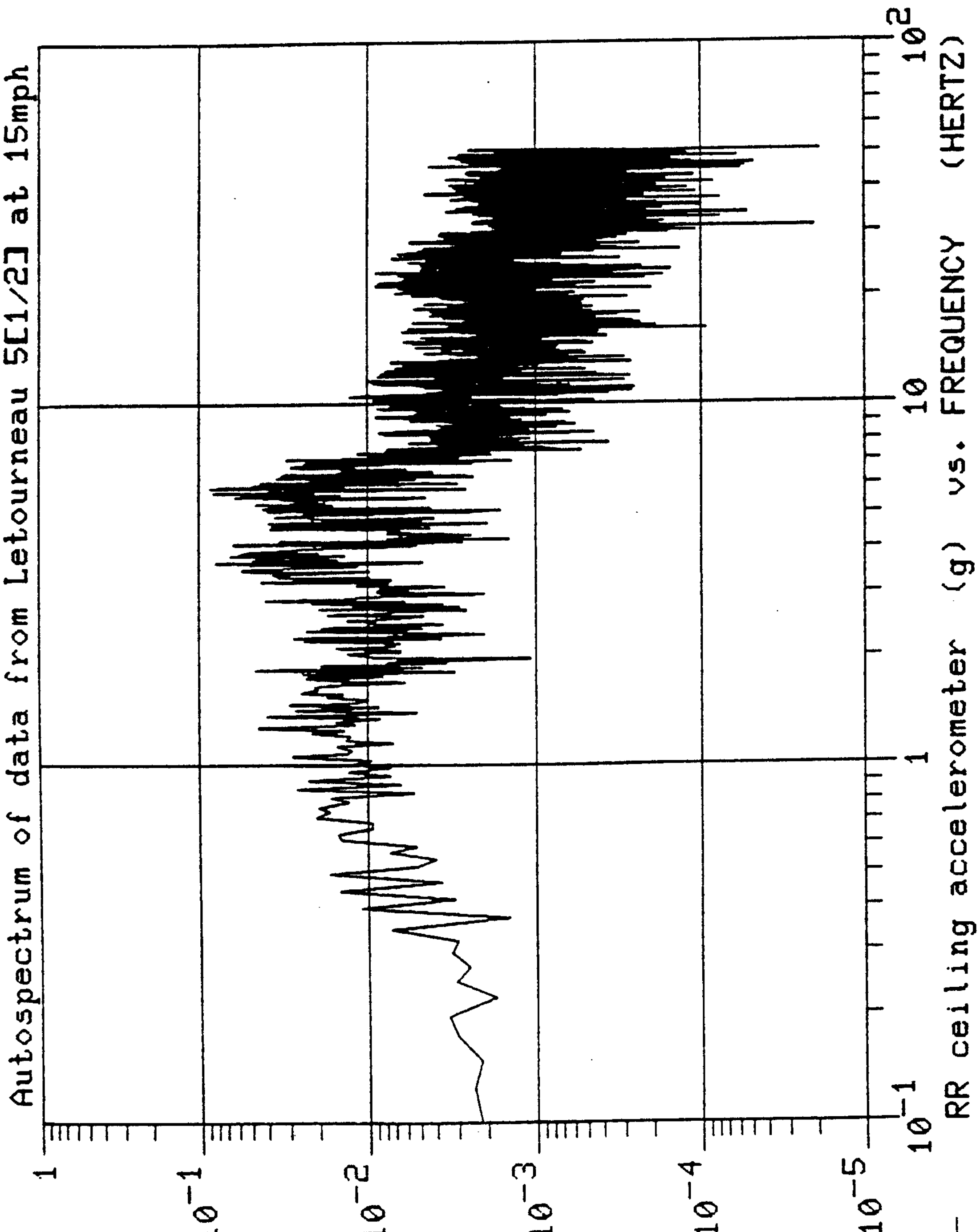

Autospectrum of data from Letourneau 5[1/2] at 15mph
RR ceiling accelerometer (g) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 61

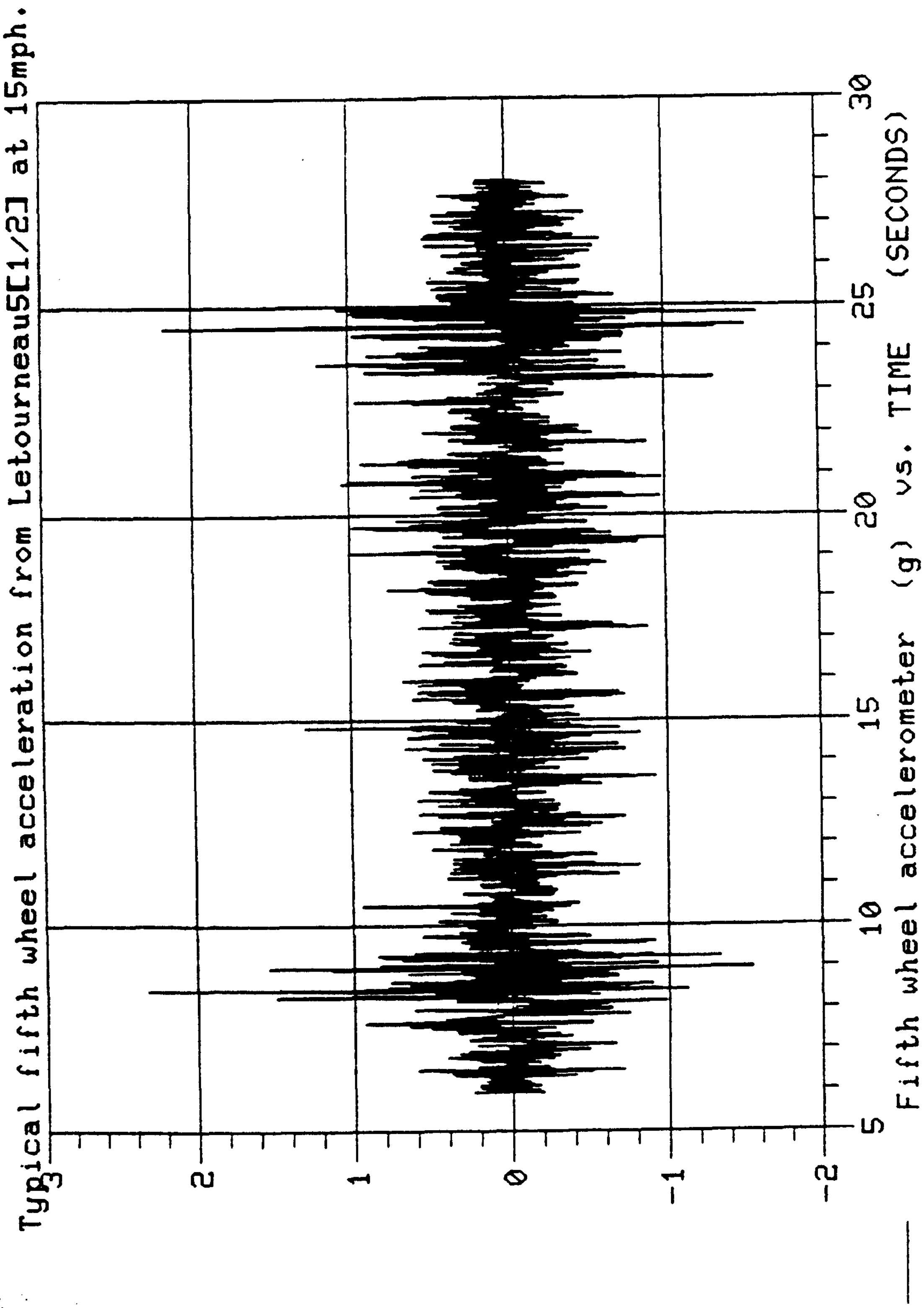

Typical fifth wheel acceleration from Letourneau5[1/2] at 15mph.
Fifth wheel accelerometer (g) vs. TIME (SECONDS)
3
2
1
0
-1
-2
5
10
15
20
25
30

Figure 62

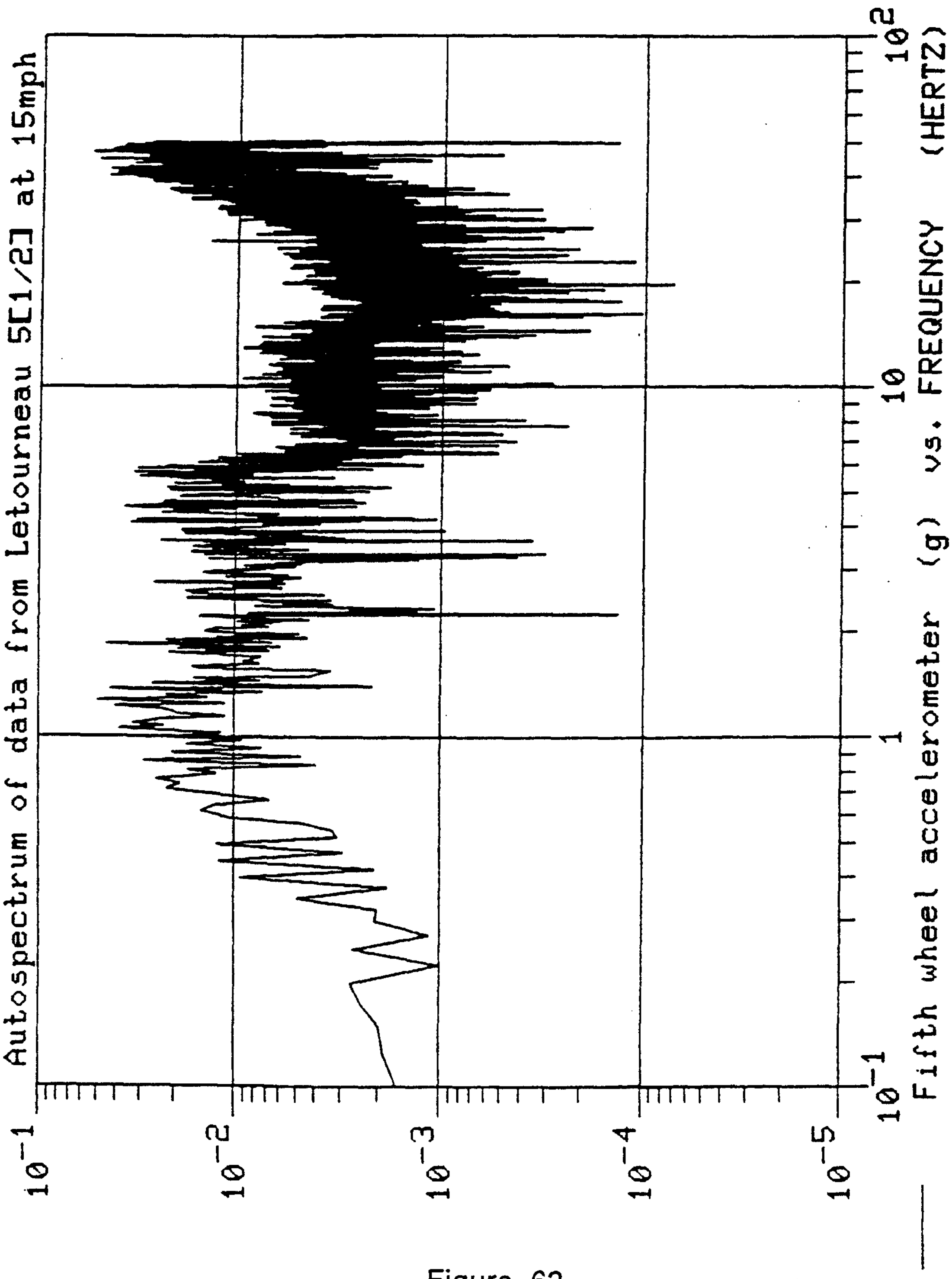

Autospectrum of data from Letourneau 5[1/2] at 15mph
Fifth wheel accelerometer (g) vs. FREQUENCY (HERTZ)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10
10^2

Figure 63

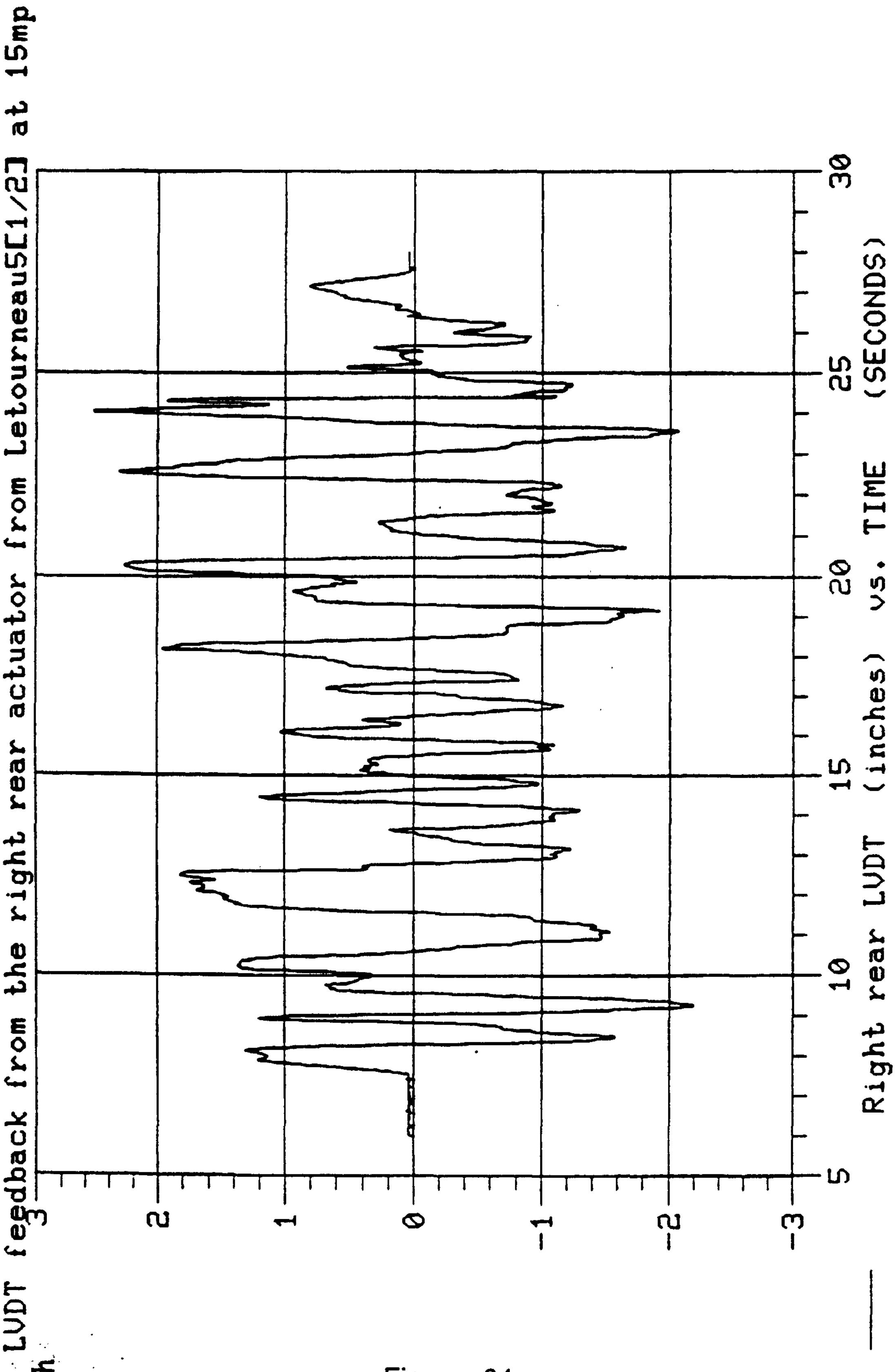

LVDT feedback from the right rear actuator from Letourneau5[1/2] at 15mph
3
2
1
0
-1
-2
-3
5
10
15
20
25
30
Right rear LVDT (inches) vs. TIME (SECONDS)

Figure 64

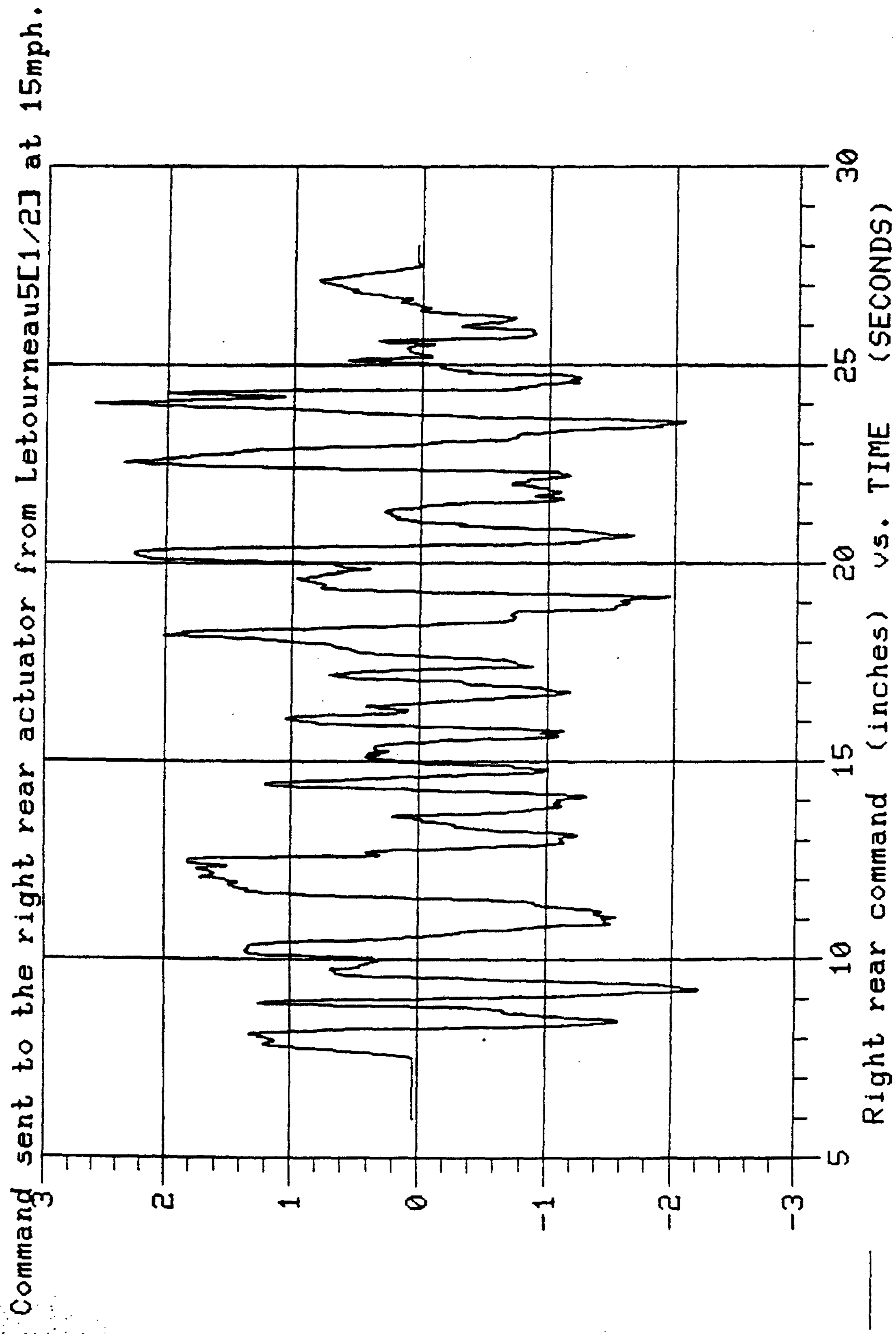
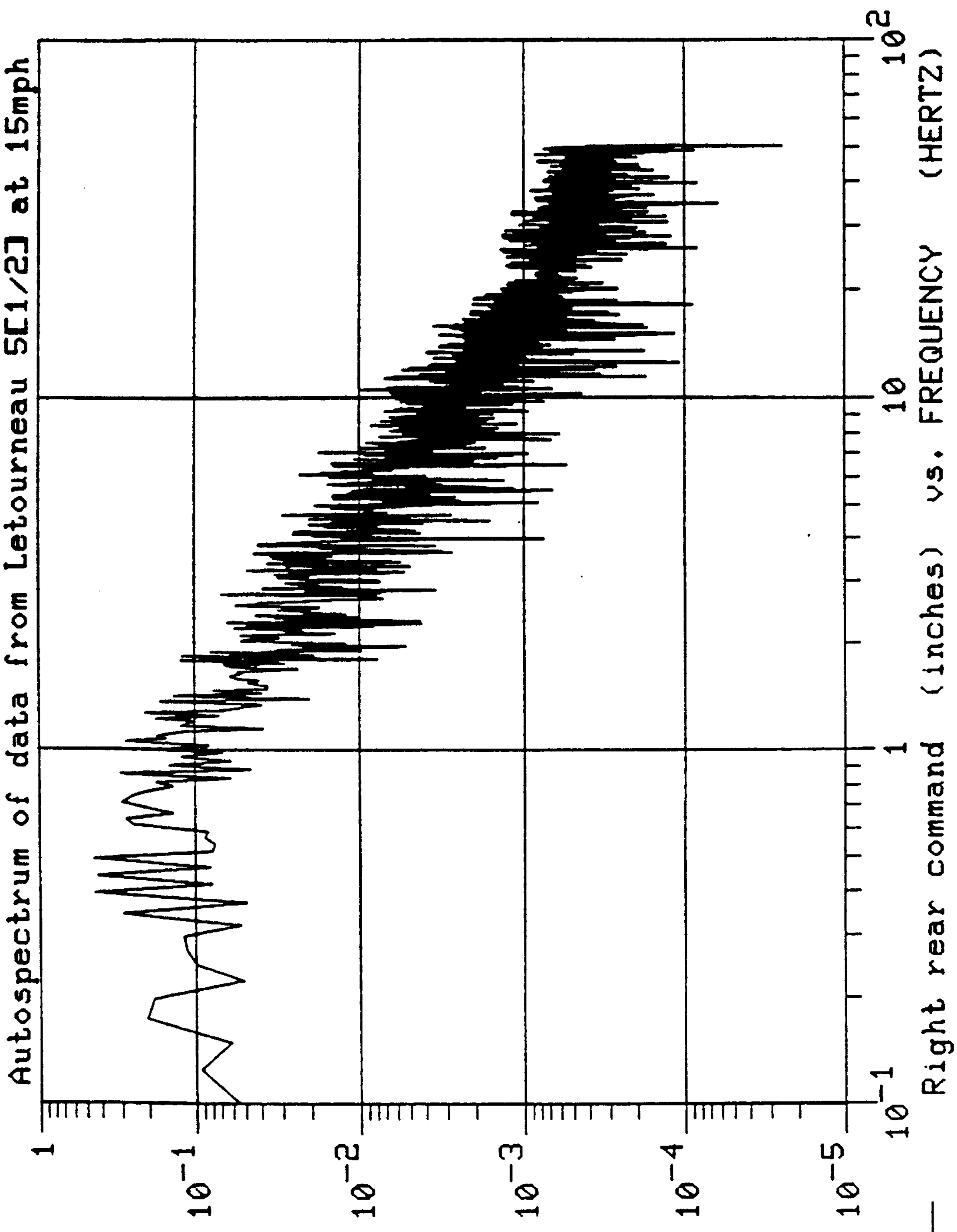

Command sent to the right rear actuator from Letourneau5[1/2] at 15mph.
3
2
1
0
-1
-2
-3
5
10
15
20
25
30
Right rear command (inches) vs. TIME (SECONDS)

Figure 65



Autospectrum of data from Letourneau 5[1/2] at 15mph
Right rear command (inches) vs. FREQUENCY (HERTZ)
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-1
1
10
10^2

Figure 66

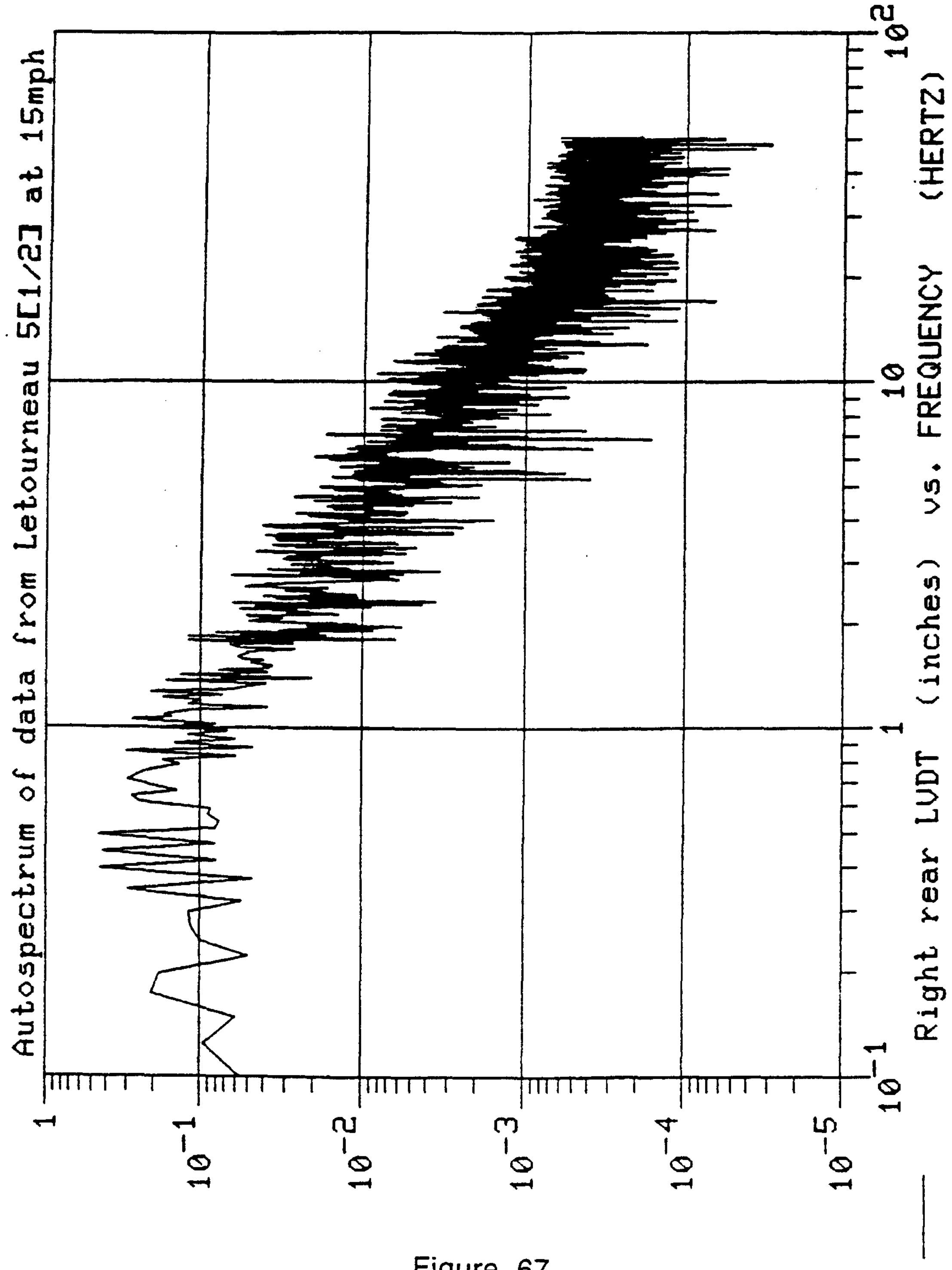

Autospectrum of data from Letourneau 5[1/2] at 15mph
Right rear LVDT (inches) vs. FREQUENCY (HERTZ)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-1}
1
10
10^{2}

Figure 67

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